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ORIGINAL ARTICLE / ARTÍCULO ORIGINAL

OPTIMAL THERMAL ANALYSIS OF CORONAVIRUS (COVID-19) TRANSMISSION DURING QUARANTINE DAYS IN PERU

ANÁLISIS TÉRMICO ÓPTIMO DE LA TRANSMISIÓN DEL CORONAVIRUS (COVID-19) DURANTE DÍAS DE CUARENTENA EN PERÚ

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ABSTRACT

In this research COVID-19 transmission is analyzed in relation to thermodynamic and energy balance between geographic areas and its correlation with possible COVID-19 transmission between two persons at least. In order to achieve parameters for medical doctors, as for example the minimal distance among two infected people, who have this virus, there were designed mathematical models that were based in statistical data to get information of COVID-19 propagation as the dependence on temperature of geographic areas, moreover the thermal effect of the minimal distance between two people avoiding COVID-19 infection. With this work, answers are sought to the questions: if it could be possible to find a relation between temperature and virus transmission? Or if it could be possible to get a correlation among thermal variables with minimal distance separation (it was described above) for two people? the goal was to find answers to these questions to support medical doctors, who are trying to find solution for COVID-19 propagation. It is worth mentioning that this research can be extended to more complex areas such as street markets, street fairs or enclosed marketplaces, where products and services are sold, moreover, not every area has an air conditioning system in Peru., This research sheds light on issues such as appropriate ventilation parameters, the minimal distance that people need to be separated to minimise virus transmission. Furthermore, some geometrical/material characteristics for air filters and ultraviolet (UV) disinfection at the entrance of the main air duct are proposed.

Keywords: COVID-19 – Modulating Functions – thermodynamic

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RESUMEN

En esta investigación se analiza la transmisión de COVID-19 por equilibrio termodinámico y energético entre áreas geográficas y su correlación con la posible transmisión de COVID-19 entre al menos dos personas. Con el fin de lograr parámetros para los médicos, como por ejemplo la distancia mínima entre dos personas infectadas que tienen este virus, se diseñaron modelos matemáticos basados en datos estadísticos para obtener información sobre la propagación de COVID-19 como la dependencia de la temperatura de áreas geográficas, además, el efecto térmico de la distancia mínima entre dos personas evitando la infección por COVID-19. Con este trabajo, se buscan respuestas a las preguntas: ¿Si fuera posible encontrar una relación entre la temperatura y la transmisión del virus? ¿O si fuera posible obtener una variable de correlación entre variables térmicas con una separación mínima de distancia (se describió anteriormente) para dos personas? Por lo tanto, se esperan respuestas a estas preguntas debido al apoyo de los médicos, que están tratando de encontrar una solución contra la propagación de COVID-19. Vale la pena mencionar que esta investigación puede extenderse a áreas más complejas como mercados y ferias abiertas al aire libre o mercados cerrados, donde se venden productos y servicios, además, no todas las áreas tienen un sistema de aire acondicionado en Perú. Sin embargo, en esta investigación se logra la técnica, cómo resolver esta tarea: obtener parámetros de ventilación apropiados como la dependencia de la distancia mínima que las personas necesitan para separarse, para evitar la transmisión del virus entre sí. Además, se sugieren algunas características geométricas / materiales para los filtros de aire y la desinfección mediante ultravioleta (UV) en la entrada del conducto de aire principal.

Palabras clave: COVID-19 – funciones moduladoras – termodinámica

INTRODUCTION

For the time, while this research is prepared, in China it was decreased the quantity of infected people. In Italy this situation leaves slowly from the maximal value of infected and deceased people. Furthermore, the situation in Peru is on the road to get its maximal value of infected people. For countries, where the health system was not enough prepared for COVID-19 and simultaneously no prepared by technical equipment to research for a vaccine, in these countries it needs to decrease infected people curve through statistical analysis of the virus treatment(MINSA, 2020).

Nevertheless, this task is so probabilistic and it depends very much from coordination between government and people. This is the reason, why in this research it is looking for a scientific calculation to warrant a parameter of distance separation between two people at least, owing to care from virus transmission (Anekal, 2009; Crammer, 2018; Bouchnita & Jebrane, 2020; Bourouiba, 2020; Fuk-Woo, 2020; Harcourt, 2020; Dai & Zhao, 2020; Kapur, 2020; Schoen, 2020). From other side, there are many questions such as, whether the temperature can be a positive factor to reduce the transmission? If really the virus can be transmitted through the air? These questions are analyzed in this research, because to find an appropriate answer that depends from parameters of every geographical area of the world, which means dynamic curve of infected people could be similar for some countries, however, can be very different with others.

As the main target of this research, it is looking for to achieve a relation of parameters that could be a support for people's interaction during COVID-19 quarantine days in Peru and after the pandemic could start to decrease the quantity of infected and deceased people. It is problematic to know, what exact distance separation must to be between two people according to avoid virus transmission. There are proposals for 1 meter, sometimes 2 meters and so on, even though, the ideal context is to be separated as maximal as possible, however, to keep isolation even also when the infected curve tends to decrease quantity. This is complicated owing to how not to not damage the economical behavior of a country. Therefore, according to continue economical tasks, it is necessary to know, what could be the ideal distance between people in markets, schools, banks and especially in Intense Care Unit (ICU) between medical doctors and patients, due to it is necessary to correlate thermal variables too.

This research is made to keep support for medical doctors, who are trying to find solutions against COVID-19, even though, in the beginning of epidemic, Peruvian hospitals were not ready to give enough attention to people in country under extreme conditions. Nevertheless, in this research is analyzed thermal characteristics for the environmental conditions of ICU room, which are correlated with thermodynamic variables of the patient, equipment around and the medical doctor. Until it is unknown a vaccine against COVID-19, the patient for this research is considered as a black box (not without a solution, due to there are many situations, when people were recovered from deep infection). Therefore, whether the main task is to keep in steady-state ICU variables of the patient, it is necessary to keep in steady-state environment condition variables too. Gray (2020) and Wang *et al.* (2020) analyzed by statistical data that people in countries with the warm climate get better recovering from the virus in contrast if to compare with the same situation in countries with the cold climate. Therefore, if warm areas of Peru could be appropriated places, where people could recover from COVID-19? Is it true and why? These questions are analyzed in the mathematical analysis.

Figure 1 shows the behavior of the infected quantity of people as the dependence of days under infection and as the dependence of temperature for three different climate behavior in Peru. Therefore, the red color curve corresponds to Piura (this is the city in Peru with the hot climate, where during almost all the year is up 30°C and this was represented in figure 1 as points *R1*, *R2* and *R3* of this curve), the blue color curve corresponds to Lima (this is the city in Peru with the warm climate, where during almost all the year is around 17°C-22°C and this was represented in figure 1 as points *B1*, *B2* and *B3* of this curve), and the green color curve corresponds to Puno (this is the city in Peru with the cold climate, where during almost all the year is down 10°C and this was represented in the figure 1 as points *G1*, *G2* and *G3* of this curve).

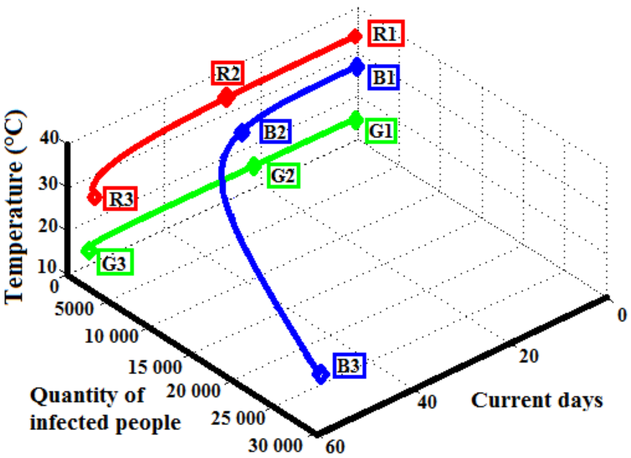

Figure 1. The quantity of infected people curve in Lima, Puno and Piura.

In figure 1 is depicted that in Piura it keeps 32°C approximately during all 60 quarantine days (it kept similar tendency until the last quarantine day too) and the total quantity of infected people did not cross number of 3000 by the official declaration of the Health Ministry of Peru (MINSA or Ministerio de Salud) (MINSA, 2020). Furthermore, it is depicted that in Lima it keeps 20°C approximately during all 60 quarantine days (it kept similar tendency until the last quarantine day too) and the total quantity of infected people did not cross number of 100000 by the official declaration of MINSA. And finally it is depicted that in Puno it keeps in average 2°C approximately during all 60 quarantine days (it kept similar tendency until the last quarantine day too) and the total quantity of infected people did not cross the number of 1000 by the official declaration of MINSA. Therefore, for cities with the hot and warm climate (Piura and Lima) as a comparison with the cities with the cold climate (Puno) it was not verified the possibility that high levels of temperature could decrease the number of infected people. In Lima were more infected people, maybe because they could not keep the distance between each other, while they were getting interactions. However, in Puno with the very cold climate, it was less quantity of infected people as the comparison with the same situation in Lima and Piura.

Furthermore, after to analyze big areas as it was described above, became some questions: if this virus can be transmitted between two people at least, even there is no contact among them? If an infected person has a high body temperature, what could be the minimal distance that other persons could be around? (ECDPCCD, 2020; Li *et al.,* 2020). If the minimal distance could have the dependence of airflow? These questions will correlate the paragraph above according to achieve a scientific result for medical doctors in the following chapter. Notwithstanding, this research can not be useful, if authorities do not keep order to apply movement rules in quarantine days. Mathematical advance that was supported in optimal solutions for thermodynamic calculations between populations and bodies of people was optimized with statistical data in order to get an optimal algorithm to achieve parameters that were described above. Moreover, this research can be used to study solutions of the virus treatment through physical parameters that were required by medical doctors and results that were achieved from the condition of the patient. That variables can be integrated to achieve a mathematical model that could be useful to control the virus.

The figure 2 represents two people as cylinders *A* and *B*. The heat transmission between each other is given because they are both heat sources as it was represented by spheres with radius *R1* and *R2*. The spheres centers and cylinders centers are not necessary to be for the same point (this is the ideal situation). Furthermore, ϕ represents the airflow from *A1* to *A2* that can not be necessary to flow from that direction. The task is to obtain the minimum separation distance *d* between both people according to avoid virus transmission.

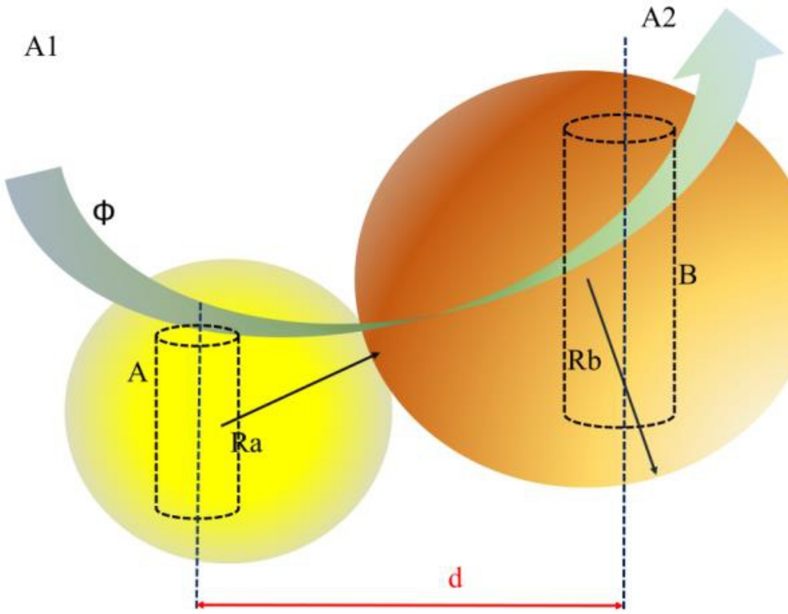

Figure 2. Scheme of the thermal interaction between two people.

The figure 3 shows thermodynamic variables correlations for ICU room, in which *R* represents the ICU room, ɸ represents the airflow inside the room (from entrance *A* and exit *B*), *V1* and *V2* represent windows, *E* depicts ICU equipment, *M* represents a medical doctor and *P* represents the patient. Therefore, it is possible to design a mathematical model according to find an explanation of the correlation of all these variables and as a consequence to prevent the virus transmission between people.

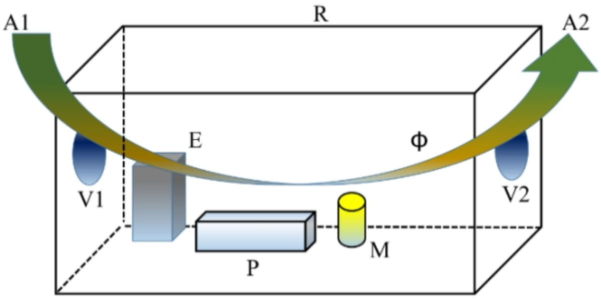

Figure 3. The scheme of thermodynamic variables correlations for icu room.

MATERIALS AND METHODS

As it was proposed in paragraphs above, thermal variables such as flow, temperature and humidity can be important parameters according to analysis virus propagation. Therefore, the minimum distance between people could not be the same value in different geographical areas, owing to the dependence of thermal variables. That is quite important due to interaction needs specific limitations according to the maximal complications of virus propagation that can be necessary to care about people. Nevertheless, economical activities can not stop as also interaction among patients and medical doctors. Therefore, it comes the question: what could be the minimal distance? To propose a model regarding minimal distance between people, there are many authors, such as Bouchnita & Jebrane (2020), that started their analysis with the Second Newton Law as it was described by the equation (1) in which for every index *i*, the mass of people is *m*, the velocity is *v* and forces are *f*.

$$m_i \frac{dv_i}{dt} = f_{if} + f_{io} + f_{iw} + \epsilon_i \qquad (1)$$

Therefore, by some consequences of Chaos Theory, it was adapted the solution for the last equation (from Chaos Theory analysis) to particular cases of COVID-19 and effects in Peru:

$$f_i = \alpha e^{(\frac{d_{ij}-d_o}{\beta})}\Gamma \qquad (2)$$

In which *Γ* is a function of internal parameters *γ* and ɸ. In this context, it was possible to get a proposal calculation to correlate *dij* as the minimal distance separation between two people (infected or not) and with *d0* as the proposed minimal distance, because of COVID-19 propagation analysis from laboratories calculations, *α* and *β* are positive constants, *γ* is a parameter between 0 and 1, ɸ is the angle between the desired velocity and force *fi* is in the movement direction. Therefore, the equation (3) shows the relation between *γ* and ɸ:

$$\Gamma = \gamma + (1-\gamma)(\frac{1+\cos\phi_{ij}}{2}) \qquad (3)$$

The last two equation solutions were analyzed and optimized as it was described in the following paragraphs. Nevertheless, it was possible to get a numerical result according to suggest minimal distance separations to avoid virus transmission in a special situation that Peruvian government is trying to cross nowadays to return social working activities, but avoiding virus transmission. However, it is necessary to analyze the mechanic of flows (air) that gets ventilation inside rooms, where people solve tasks by interaction. It means, it is necessary to achieve a numerical understanding of airspeed, airflow, temperature, humidity. All of them are correlated with the minimal separation distance between people.

Notwithstanding, as it was proposed by Anekal (2009), the dynamic of virus transmission can be described by the diffusion equation (4):

$$\frac{\partial V_f}{\partial t} + v\nabla V_f = D_{vf}\nabla^2 V_f \qquad (4)$$

In which, *Vf* is the virus concentration in the fluid, *v* is the velocity fluid, *Dvf* is the virus diffusivity in the fluid layer. Moreover, the solution is given by the equation (5):

$$V_f(x,t) = \frac{4V_{f0}}{\pi}\sum_{n=0}^{\infty}\frac{1}{2n+1}e^{-D\frac{\pi^2(2n+1)^2 t}{l^2}}\sin(\frac{(2n+1)\pi x}{l}) \qquad (5)$$

for which *n*, *D* and *l* are constants to fix space *x* and *t* is the connotation of time.

Therefore, by correlating the last both equations and by Modulating Functions, the general solution can be achieved as equation (6):

$$P^n y(t) + \sum_{j=1}^{n} a_j P^{n-j} y(t) = \sum_{j=1}^{n} b_j P^{n-j} u(t) + e(t) \qquad (6)$$

However, as it was proposed by Modulating Function solution analysis for diffusion equation (Anekal, 2009), it was solved diffusion equation through this methodology due to get adapted models to specific applications, such as coefficients solutions can get information of geometrical, thermal and mechanical parameters, which can be adjusted to necessities and applications.

That is the reason, why Modulating Function in this analysis gives plenty strategies.

The equation (7) describes space fractional advection dispersion equation (Aldoghaither & Da-Yan, 2015):(7) therefore, it is proposing by author (Aldoghaither & Da-Yan, 2015): (8)in which,

$$\frac{\partial c(x,t)}{\partial dt} + v(x)\frac{\partial c(x)}{\partial dx} - d(x)\frac{\partial c(x)^\alpha}{\partial dx^\alpha} = r(x,t) \qquad (7)$$

therefore, it is proposing by author (Aldoghaither & Da-Yan, 2015):

$$\frac{\partial^\alpha}{\partial x^\alpha}f(x) = \frac{1}{\Gamma(n-\alpha)}\frac{d^n}{dx^n}\int_{x=0}^{x}(x-t)^{n-\alpha-1}f(t)dt \qquad (8)$$

in which, ϕ is the Modulating Function, also:

$$\int_{x=0}^{I} g(I-x)\frac{\partial^\alpha f(x)}{\partial x^\alpha}dx = \int_{x=0}^{I}\frac{\partial^\alpha g(x)}{\partial x^\alpha}f(I-x)dx \qquad (9)$$

also

$$\frac{\partial^\alpha}{\partial\alpha}\frac{\partial^\alpha f(x)}{\partial x^\alpha} = \psi_0(n-\alpha)\frac{\partial^\alpha}{\partial\alpha}\frac{\partial^\alpha f(x)}{\partial x^\alpha} - G \qquad (10)$$

in which:

$$G = \frac{1}{\Gamma(n-\alpha)}\frac{d^n}{dx^n}\int_{x=0}^{x}(x-t)^{n-\alpha-1}\ln(x-t)\,f(t)dt \qquad (11)$$

Finally, according to solve the diffusion equation, there were obtained the coefficients of the general diffusion equation:

$$v(x) = \sum_{k=1}^{k_0} v_k f_k(x) \qquad (12)$$

Moreover,

$$d(x) = \sum_{k=1}^{k_0} pk f_k(x) \qquad (13)$$

therefore:

$$QX = Y \qquad (14)$$

in which by author (Aldoghaither & Da-Yan, 2015), obtained:

$$Q = \begin{pmatrix} q_{11} & q_{12} & q_{13} & \cdots & q_{1k_1+k_2} \\ q_{21} & q_{22} & q_{23} & \cdots & q_{2k_1+k_2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ q_{M1} & q_{M2} & q_{M3} & \cdots & q_{Mk_1+k_2} \end{pmatrix} \quad (15)$$

Also,

$$X = \begin{pmatrix} v_1 \\ v_2 \\ v_3 \\ \vdots \\ v_{k1} \\ d_1 \\ d_2 \\ d_3 \\ \vdots \\ d_{k2} \end{pmatrix} \quad (16)$$

also

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_M \end{pmatrix} \quad (17)$$

Furthermore by author (Aldoghaither & Da-Yan, 2015),

$$q_{m,k} = \begin{cases} \int_{x=0}^{L_1} \frac{\partial f_k(x)\phi_m(L_1-x)}{\partial x} c(x,t)dx & ,k = 1,2,\dots,k_1 \\ \int_{x=0}^{L_1} \frac{\partial^\alpha \phi_m(x)}{\partial x} c(L_1-x,t)dx & ,k = k_1+1, k_1+2,\dots,k_1+k_2 \end{cases} \quad (18)$$

moreover,

$$y_m = -\int_{x=0}^{L_1} \phi_m(L_1-x)(r(x,t)\frac{\partial c(x,t)}{\partial t})dx \quad (19)$$

and

$$\phi_{m,k}(L_1 - x) = p_k(x)\phi_m(L_1 - x) \quad (20)$$

Therefore,

$$X = (Q^TQ)^{-1}Q^TY \quad (21)$$

Furthermore, it is known the equation (22) (IUVA, 2020), in which C is indoor pollutant concentration,

$$C = C_0 e^{-\frac{qn}{v}t} + \frac{M}{qn}(1 - e^{-\frac{qn}{v}t}) \quad (22)$$

in which, M is the indoor pollutant generation, v is the room volume, n is the air purifier collection efficiency, t is the time, q is the air purifier flow volume.

According to optimize the solutions of the proposed models, it was analyzed the error among a desired value (theoretical solution) and obtained the equation solution (23), where solution error analysis $e(t)$ is the discrete error, and V keeps the Fourier series coefficients.

$$e_n(m) = \sum_{k=m}^{n+m} \alpha(k,m,\theta_a)V(k) \quad (23)$$

furthermore, α is the frequency parameter function:

$$\alpha(k,m,\theta_a) = C_{k-m}\sum_{j=0}^{n} a_j(jk\omega_0)^{n-j} \quad (24)$$

for which, the nonlinear model for error analysis is given by equation (25):

$$\sum_{j=0}^{n_1}\sum_{k=1}^{n_2} g_j(\theta)F_{jk}(u,y)P_{jk}(p)E_k(u,y) = 0 \quad (25)$$

therefore, the costing function is given by equation (26):

$$J(\theta) = \sum_{j=0}^{n_1}\sum_{k=0}^{n_1} r_{jk}g_j(\theta)g_k(\theta) \quad (26)$$

also, according to get parameters of the main model it was achieved the derivation:

$$\frac{\partial J}{\partial \theta} = (Y - \Gamma\theta)^T W^{-1}(Y - \Gamma\theta) \quad (27)$$

where parameters θ are showed in equation (28) as the dependence of the adaptive coefficients W.

$$\theta = (\Gamma^T W^{-1}\Gamma)^{-1}\Gamma^T W^{-1} Y \quad (28)$$

And the response estimation Y is given by equation (29):

$$\hat{Y} = X(X^T X)^{-1} X^T Y \quad (29)$$

Finally, the adaptive response estimation is given by equation (30):

$$\hat{Y}w = X(X^T W^{-1} X)^{-1} X^T W^{-1} Y \quad (30)$$

RESULTS AND DISCUSSION

After to achieve the mathematical model to estimate the airflow and its optimal values for rooms of 100 meters square approximately, there were prepared a summary table 1 to make calculation of the physical variables (from the mathematical models, which were analyzed in section 3), moreover curves that are shown in the following figures.

Table 1. Calculated Physical Parameters and Optimal Estimated Airflow.

$V_s(\frac{m}{s})$	$\varphi(\frac{m^3}{s})$	$\widehat{\varphi_0}(\frac{m^3}{s})$	$T(°C)$	$H(\%)$	$M_d(m)$
0.10	0.04	0.043	25	70	1
0.12	0.05	0.047	23	65	2
0.14	0.06	0.059	21	60	4
0.16	0.07	0.070	19	55	6
0.18	0.08	0.081	17	50	8

In figure 4 is shown the curve of airflow as the dependence on airspeed and temperature (blue color curve) and its optimal curve (red color curve).

It is possible to identify that airflow is increasing while airspeed is increasing too. However, in the other side the temperature is decreasing. Therefore, the optimal value for airflow keeps similar behavior of the calculated airflow (from O_1 to O_2) that can be interpreted as the suggestion to reduce the temperature of the room progressively, the airflow is increasing and the airspeed is increasing too.

In figure 5 is shown the curve of airflow as the dependence on humidity and temperature (blue color curve) and its optimal curve (red color curve).

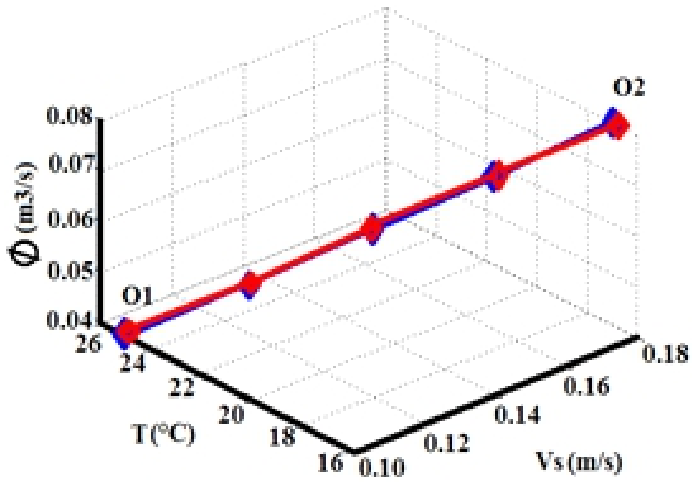

Figure 4. Airflow curve (blue color) and optimized airflow curve (red color) as the dependence on airspeed and temperature.

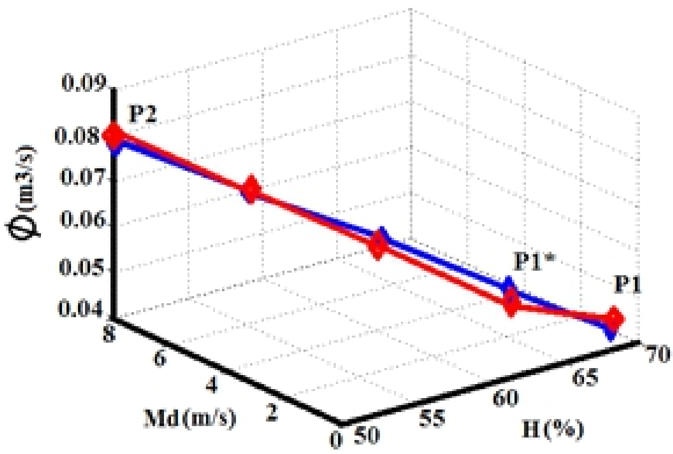

Figure 5. Airflow curve (blue color) and optimized airflow curve (red color) as the dependence on humidity and minimal separation distance.

It is possible to understand that airflow is increasing while the minimal distance separation between people is increasing too, notwithstanding, in opposite side the relative humidity percent is decreasing. Hence, the optimal value of the airflow keeps linearity response behavior (from P_1 to P_2), that can be interpreted as the suggestion to increase humidity of the room progressively, the airflow decreasing and the minimal distance separation is decreasing too.

In this research, there were analyzed 3 equations models that were based in chaos theory application, according to suggest the minimal interaction distance between people. Diffusion equation analysis, according to calculate airflow parameters and thermodynamic parameters configurations and as the consequence to keep appropriated ventilation in rooms, where people are under high possibilities to get virus transmission.

It is suggested to expand this study for open areas, such as markets or rooms without air conditioning system, but they only could use fans to achieve appropriated correlation among the physical variables as it was proposed in this research. This future research can help to suggest appropriated parameters, which authorities could try to apply according to care people under this epidemic. Finally, by UV propagation, it can be proposed a cleaning procedure owing to enhance the protection against COVID-19 (as a result of equation 22)(IUVA, 2020).

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