Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System

II- Computation of power and the entropy source of the cardio pulmonary system

BOGDAN BORCILA[1]*, STOIAN PETRESCU[1], MONICA COSTEA[1], VALERIA PETRESCU[1], ROMI BOLOHAN[2]

[1]University Politehnica of Bucharest, 313 Splaiul Independentei, 060042, Bucharest, Romania

[2]Emergency Clinical Center for Cardiovascular Diseases Dr. Constantin Zamfir, Clinic of Cardiology, Electrophysiology and Arrythmology, 134 Calea Plevnei, 010242, Bucharest, Romania

The paper presents the results of the recent studies and research conducted within the Quantum Biological Thermodynamics with Finite Speed on the calculation and interpretation of the Cardio-Pulmonary System performance. Thus, based on the new PV/Px diagram developed for the Cardio-Respiratory System, an original Scheme for calculating the Mechanical Work and Power of the Heart/Lungs has been developed. The new Calculation Scheme allows to study the variation of the Heart and Lungs parameters for each person, in Quantum States and in Processes with and without Quantum Jump. Based on the values calculated in each Stationary State, for the cases studied, the diagrams of the Mechanical Work, of the total Power and the Entropy Source for the Cardio-Pulmonary System, as functions of the Frequencies of the Heart (F_H), and the Lungs (F_L), the maximum systolic pressure and body mass of the person were thus constructed. The study and interpretation of these diagrams - which are novel elements - provides information on interactions within the Cardio-Pulmonary System or between it and the entire body, particularly useful in bioengineering for optimized and personalized design of artificial organs.

Keywords: Quantum Biological Thermodynamics with Finite Speed, Cardio-Pulmonary System, Processes with and without a Quantum Jump, Stationary States, artificial Organs, Mechanical Work and Power computation, Entropy Source

Based on the main achievements of the Thermodynamics with Finite Speed extension to Quantum Biological Thermodynamics with Finite Speed [1-15], namely: *PV/Px* diagram for Heart and Lungs functioning; the specific processes in the Cardio-Pulmonary System; the equations describing them and the diagrams for the study of *Stationary States* and *Processes with and without Quantum Jump*, experimental studies and researches on the states and interactions Heart-Lungs with the support of a significant number of persons (about 130, ages between 20 and 80 years) have been continued in the last 3 years. Among them, the *PV/Px* diagram for the Cardio-Pulmonary System has been developed and has led to an original *Scheme for analytical calculation of the Mechanical Work and Power consumption of the Heart/Lungs*. On the basis of the performance evaluation with the *new calculation scheme*, the diagrams of Mechanical Work, total Power and Entropy Sources for the Cardio-Pulmonary System as functions of the Heart, F_H, and Lungs, F_L, Frequencies, the maximum systolic pressure and body mass of the person were built. The new diagrams constructed, using the values calculated with the discovered analytical formulas, facilitate the study of the variation of the two parameters of the Heart and Lungs, in Stationary Quantum States, customized to each person. The study and interpretation of these diagrams - *which are novel elements* - provides information on *Heart-Lungs* interactions on the one hand and the *Cardio-Pulmonary System - the entire body* on the other hand, particularly useful in bioengineering for optimized and personalized design of organs according to the physiological particularities of each patient.

* *email: bbd1188@yahoo.com, Phone: 0727978091*

Experimental part

Scheme for calculation of Mechanical Work, Power and Source of Entropy of the Cardio-Pulmonary System

The Power of the Heart [5] can be expressed using the new chart *PV/Px* from QBTFSCPS by taking into account the losses caused by throttling in the valves of the Heart.

On average, the dimensions of the human Heart are: h (height)≅0.12 m; l (width)≅g (thickness)≅0.08 m, according to the literature [16-25].

To simplify the calculations, the Heart was considered as having the shape of a circular truncated cone with the smaller base downward (fig. 1). The bases diameters of the circular truncated cone (large and small) are $D=2 . R = l$ and $d=2 . r$ and its height is h. In order to keep the human Heart dimensional proportionality as rigorous as possible, one considers that $D=4 . d$. Therefore, the relationship between the radii of the two bases is $R=4\cdot r$.

During Cardio-Pulmonary System operation, the Cardiac Output (flow rate), CO [m^3/min.], is considered to be 5÷6 m^3/min at rest., while during a great effort it could reach 25÷35 m^3/min. Generally, the amount of blood of a person is about 7÷8% of its body mass. Cardiac Output is pumped by the Heart every minute and can be determined by various methods (Fick, dilution, echocardiography, impedance cardiography) [16-25]. We have noted the percentage of body mass that represents the amount of blood in a person's body withkB=0.07÷0.08. For calculations we considered k_B=0.075.

Furthermore, according to the literature [22], the blood density at 37 °C is ρ_B=1060 kg/m^3.

The total blood Volume for a person with a mean physical constitution [17, 22] is calculated as follows:

$$V_{TB} = \frac{k_B \cdot m_{body}}{\rho_B} \ [\mathrm{m}^3] \quad (1)$$

where m_{body} is the mass of the body [kg].

The Cardiac Output, *CO*, is determined based on the relation:

$$CO = \frac{V_{TB}}{t} \; [m^3/min] \qquad (2)$$

where t = 1 min is the time frame in which the Heart ejects the entire Heart rate into the body [16, 19, 20].

Therefore, at a Stroke (oscillation) of the Heart, the Cardiac Output pumped (volume/stroke), CO_0 [m^3/stroke], results when also considering eq. (2) as:

$$CO_0 = \frac{CO}{N_s} = \frac{V_{TB}}{N_s \cdot t} = \frac{k_B \cdot m_{body}}{N_s \cdot t \cdot \rho_B} \qquad (3)$$

where N_s is the number of Strokes per minute of the Heart [strokes/min], so that N_s = F_H, with F_H, Frequency of the Heart [osc/min].

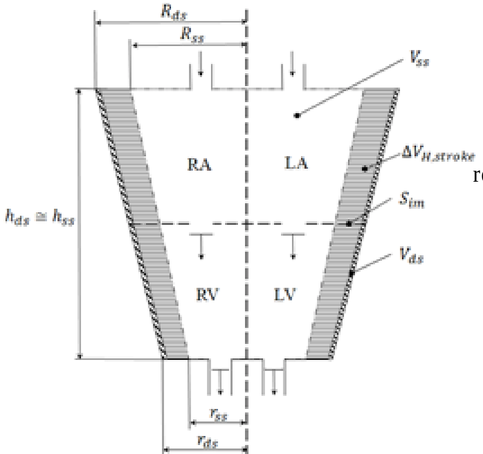

Fig. 1. The schematic representation of the Heart functioning

We consider V_{ds} - the Volume of the Heart during the diastole and V_{ss} - the Volume of the Heart immediately after the systole. Thus, during a complete pulse of the Heart we have:

$$V_{ds} - V_{ss} = CO_0 \; [m^3/stroke] \qquad (4)$$

$$V_{ds} = \frac{\pi \cdot h_{ds}}{3} \cdot \left(R_{ds}^2 + r_{ds}^2 + R_{ds} \cdot r_{ds}\right) = \frac{\pi \cdot h_{ds}}{3} \cdot \left(R_{ds}^2 + \frac{R_{ds}^2}{16} + \frac{R_{ds}^2}{4}\right) \qquad (5)$$

Finally, it results:

$$V_{ds} = \frac{7 \cdot \pi \cdot h_{ds} \cdot R_{ds}^2}{16} \qquad (6)$$

Similarly, one gets:

$$V_{ss} = \frac{7 \cdot \pi \cdot h_{ss} \cdot R_{ss}^2}{16} \qquad (7)$$

where:

- $R_{ds} = l_{ds}/2$ is the large radius of the truncated cone during the diastole [m];
- h_{ds} - Heart height during the diastole [m];
- $R_{ss} = l_{ss}/2$ the large radius of the base of the truncated cone immediately after the systole [m];
- h_{ss} - the Heart height immediately after the systole [m].

To simplify the calculations, we considered $h_{ds} \cong h_{ss} = h$ with respect to the Volume of blood pumped from the Heart during an oscillation and together with eqs. (3) and (4) it results:

$$V_{ds} - V_{ss} = \frac{7 \cdot \pi \cdot h}{16} \cdot \left(R_{ds}^2 - R_{ss}^2\right) = \frac{V_{TB}}{F_H \cdot t} \qquad (8)$$

By combining eq. (8) with (1), one gets:

$$R_{ds}^2 - R_{ss}^2 = \frac{16 \cdot k_B \cdot m_{body}}{7 \cdot \pi \cdot h \cdot t \cdot F_H \cdot \rho_B} \qquad (9)$$

and

$$R_{ss} = \sqrt{R_{ds}^2 - \frac{16 \cdot k_B \cdot m_{body}}{7 \cdot \pi \cdot h \cdot t \cdot F_H \cdot \rho_B}} \; [m] \qquad (10)$$

The expansion of the Heart (the dimensional variation on the three axes *xyz* considered equal), z_H [m], is:

$$z_H = 3\left(R_{ds} - R_{ss}\right) = 3\left(R_{ds} - \sqrt{R_{ds}^2 - \frac{16 \cdot k_B \cdot m_{body}}{7 \cdot \pi \cdot h \cdot t \cdot F_H \cdot \rho_B}}\right) \qquad (11)$$

By taking into account eqs. (3) and (8), the change of the Heart Volume at a Pulsation (Stroke) can be also expressed as:

$$CO_o = \Delta V_{H,\,stroke} = V_{ds} - V_{ss} \qquad (12)$$

The Mechanical Work of the Heart on one oscillation is determined as follows:

$$W_{t,H} = \Delta P_{t,H} \cdot \frac{k_B \cdot m_{body}}{F_H \cdot t \cdot \rho_B} \; [J] \qquad (13)$$

where $\Delta P_{t,H}$ represents the total pressure variation in the Heart compartments during a complete pulse and corresponds to:

$$\Delta P_{t,H} = \Delta P_{H,left} + \Delta P_{H,right} \; [N/m^2] \qquad (14)$$

with:

$$\Delta P_{H,left} = \left(\frac{P_{H,s,max,left} - P_{H,LA}}{760}\right) \cdot 10^5 + 3 \cdot \Delta P_{H,thr} \qquad (15)$$

$$\Delta P_{H,right} = \left(\frac{P_{H,s,max,right} - P_{H,RA,}}{760}\right) \cdot 10^5 + 3 \cdot \Delta P_{H,thr} \qquad (16)$$

where:

$P_{H,s,max,left}$ - the maximum systolic Pressure measured with a blood pressure monitor on the left side of the Heart (mmHg);

-$P_{H,LA}$ - the Pressure (7÷12 mmHg) at the circulation of the oxygenated blood through the four pulmonary veins in the left auricle;

- $P_{H,s,max,right}$ - maximal systolic Pressure (15÷25 mmHg) at the circulation of venous blood through the pulmonary artery to the right ventricle into the two Lungs - through the small and larger left pulmonary arteries [mmHg];

-$P_{H,RA}$ - the blood Pressure to pass from the cave veins into the right auricle (0÷9 mmHg) [16].

Pressure losses by throttling through the valves, $\Delta P_{H,thr}$ [Pa], can be calculated by taking into account the laws of conservation the mass of fluid (Continuity Equation) and preserving the energy of the fluid (Bernoulli Equation), which circulates through a Pressure reduction section [26]:

$$\Delta P_{H,thr} = \frac{w_B{}^2 \cdot \rho_B \cdot \left[\left(\frac{S_{H,avr}}{S_v}\right)^2 - 1\right]}{2} \qquad (17)$$

in which w_B [m/s] - the mean speed of the blood during its flow through the Heart compartments, $S_{H,avr}$ - the circular crown surface of the medial cross section of the truncated cone to the Volume variation of the Heart between the systole and diastole, and S_v - the mean surface of a valve of the Heart with diameter $d_v \cong 0.027$ m [16].

The circular crown surface of the medial cross section of the truncated cone was calculated to respect cardiac output (CO_o) ejected during the Heart systole:

$$S_{H,avr} \cong 2 \cdot \pi \cdot R_{ds} \cdot z_H \; [m^2] \qquad (18)$$

After replacing eq. (18) in (17) and explicit writing of the surface S_v it results:

$$\Delta P_{H,thr} = \frac{w_B^2 \cdot \rho_B \cdot \left[\left(\frac{8 \cdot R_{ds} \cdot z_H}{d_v^2}\right)^2 - 1\right]}{2} \quad (19)$$

The blood Volumetric Flow rate (Cardiac Output, CO) can be also determined as [26]:

$$CO = S_{H,avr} \cdot w_B \quad (20)$$

where the transversal cross-section of the crown results geometrically from:

$$\Delta V_{H,stroke} = S_{H,avr} \cdot h = \frac{CO}{N_c} = \frac{60 \cdot CO}{F_H} \quad (21)$$

$$S_{H,avr} = \frac{60 \cdot CO}{F_H \cdot h} \quad (22)$$

By combining eqs. (20) and (22) it results:

$$w_B = \frac{CO}{\frac{60 \cdot CO}{F_H \cdot h}} = \frac{F_H}{60} \cdot h \ \ [\mathrm{m/s}] \quad (23)$$

The total Heart Power, $W_{t,H}$, based on eq. (13) is computer taking into account the losses done by throttling: Based eq. (14), is computed the total Heart Power, $W_{t,H}$, taking into account the losses done by throttling:

$$\dot{W}_{t,H} = W_{t,H} \cdot \frac{F_H}{60} \ [\mathrm{W}] \quad (24)$$

The computation of the Power of the Lungs is presented hereafter.

The Current Volume or, as it is called in the physiology literature [16-28], *Tidal Volume*,

V_T of the air entering the Lungs at an inhalation is $(0.5 \div 0.8) \cdot 10^{-3}$ [m^3/stroke].

The total Volume V_t that enters and exits the Lungs every minute is $7.5 \div 12 \times 10^{-3}$ m^3,with effort conditions up to $240 \cdot 10^{-3}$ [m^3].

From the amount of inhaled air, 0.2÷0.35 remains in the residual anatomical space of the Lungs. This percentage is denoted by k_a and $k_a = 0.2$ will be taken as for the calculations. Thus, the Volume of fresh air reaching the respiratory area of the Lungs in one minute, $\Delta V_{t,L}$ [m^3/min], is:

$$\Delta V_{t,L} = \frac{V_t - k_a \cdot V_t}{t} = \frac{V_t (1 - k_a)}{t} \quad (25)$$

where t = 1 min, and for the total Volume entering and leaving the Lungs every minute, an average value of $V_t = 0.75 \cdot 10^{-3}$ m^3/min will be considered.

To simplify the calculations, it is conventionally considered that each of the two Lungs has the form of a cylinder with the following dimensions: the height h_L = 0.25 m and the radius at the time of the air intake r_i = 0.062 m (fig. 2.) [23]. These dimensions correspond to the statistics according to which the Volume of the two Lungs for a person with average physical characteristics is about $6 \cdot 10^{-3}$ m^3 [23].

Normal expiratory rest phase is passive (without Energy consumption) as opposed to the inhale, in which it actively takes place muscle contraction and Power consumption. The Volumes and airflows take into account a correction factor, which brings the air (gas) to body temperature and the pressure of saturated gas with water vapors.

For a single Lung the change in the Volume within one minute is:

$$\Delta V_{L1} = \frac{1}{2} \cdot V_{t,L} = \frac{V_t (1 - k_a)}{2 \cdot t} \ [\mathrm{m^3/min}] \quad (26)$$

The current Volume entering into the Lung at an inhalation (Stroke) is:

$$V_T = \frac{\Delta V_{L1}}{F_L} \ [\mathrm{m^3/stroke}] \quad (27)$$

where: F_L represents the respiration Frequency [osc / min].

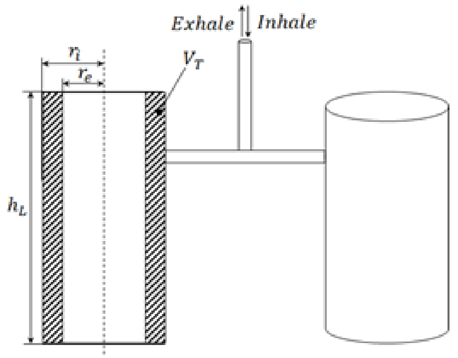

Fig. 2. The schematic representation of the Lungs functioning

By combining eqs. (26) and (27) and following the notation from figure 2, it results:

$$\frac{(1 - k_a) \cdot V_t}{2 \cdot t \cdot F_L} = V_i - V_e = \pi r_i^2 \cdot h_L - \pi r_e^2 \cdot h_L = \pi \cdot h_L \cdot \left(r_i^2 - r_e^2\right) \quad (28)$$

where: V_i - Lung Volume after inhalation [m^3]; V_e - Lung Volume after expiration [m^3]; r_i - inhalation radius [m]; r_e - radius at expiration [m].

From eq. (28) we compute:

$$r_e = \sqrt{r_i^2 - \frac{(1 - k_a) \cdot V_t}{2 \cdot \pi \cdot t \cdot F_L \cdot h_L}} \quad (29)$$

Therefore, the Stroke of the Lung, z_L [m] (the dimensional change considered equal on the three *xyz* axes) is:

$$z_L = 3(r_i - r_e) = 3\left(r_i - \sqrt{r_i^2 - \frac{(1 - k_a) \cdot V_t}{2 \cdot \pi \cdot t \cdot F_L \cdot h_L}}\right) \quad (30)$$

At the beginning of an inhalation at rest, the Volume of the chest increases and the air Pressure in the airway becomes lower than the atmospheric Pressure with 3÷4 mmHg, so that air enters the airways and Lungs. In the initial phase of exhalation, the inspiratory muscles relax, and the chest tends to return to the resting size. Therefore, in the Lungs and airways, the Pressure is higher by 3÷8 mmHg than the atmospheric Pressure [18]. Thus, the mean value of 757 mmHg and 765 mmHg, respectively, were considered in the computational scheme for the Pressures into the respiratory tract and Lungs at inhalation and expiration.

The Mechanical Work of the Lung for breathing is calculated with the relation:

$$W_{L1} = \Delta P_{i,e} \cdot \frac{\Delta V_{L1}}{F_L} \ [\mathrm{J}] \quad (31)$$

where $\Delta P_{i,e} = P_e - P_i$ =765-757=8mmHg. =1066.6 Pa. The atmospheric Pressure of P_a =760mmHg = 101325 Pa is considered.

The total Mechanical Work of the Lung is calculated taking into account the Pressure losses done by throttling:

$$W_{t,L1} = W_{L1} + W_{L,thr} \quad (32)$$

The Mechanical Work lost by throttling:

$$W_{L,thr} = \Delta P_{L,thr} \cdot A_{L,tot} \cdot z_L \ \text{[J]} \qquad (33)$$

where $A_{L,tot}$ represents the total area of the Lungs [m^2].

Similarly as in the case of the Heart eq. (19), the Pressure drop caused by the throttling of air in the Lungs, $\Delta P_{L,thr}$[Pa] is calculated by the formula:

$$\Delta P_{L,thr} = \frac{w_{air}^{2} \cdot \rho_{air} \cdot \left[\left(\frac{8 \cdot r_i \cdot z_L}{d^2_{avr,L}} \right)^2 - 1 \right]}{2} \qquad (34)$$

where: ρ_{air} = 1.153 kg / m^3 - air density at 33°C; $d_{avr,L}$=0.00769 m -the weighted average of the tracheal diameters (about 18 mm) and primary bronchi (2 x 12.2 mm), secondary ((3 + 2) x 8.3 mm), segmental (8 +7) x approx. 5.6 mm); w_{air} is the air Speed in the Lungs [m/s] and it is determined as:

$$w_{air} = \frac{F_L}{60} \cdot h_L \ \text{[m/s]} \qquad (35)$$

The total Mechanical Work of the Lungs is:

$$W_{t,L} = 2 \cdot W_{t,L1} \qquad (36)$$

The Power of the Lung at one breath is computed in the following way:

$$\dot{W}_{L1} = W_{L1} \cdot \frac{F_L}{60} \ \text{[W]} \qquad (37)$$

The total Lung Power, $\dot{W}_{t,L1}$, taking into account the losses done by throttling, is calculated with the equation:

$$\dot{W}_{t,L1} = \dot{W}_{L1} + \dot{W}_{L,thr} \ \text{[W]} \qquad (38)$$

where $\dot{W}_{L,thr}$ is the Power consumed by throttling the gas (air) into the Lungs.

Based eq. (36), we compute the total Lung Power, $\dot{W}_{t,L}$, taking into account the losses done by throttling:

$$\dot{W}_{t,L} = W_{t,L} \cdot \frac{F_L}{60} \ \text{[W]} \qquad (39)$$

The total Mechanical Work of the Cardio-Pulmonary System is calculated based on eqs. (13) and (36):

$$W_{t,CPS} = W_{t,H} + W_{t,L} \ \text{[J]} \qquad (40)$$

The total Power of the Cardio-Pulmonary System is obtained by summing eqs. (24) and (39):

$$\dot{W}_{t,CPS} = \dot{W}_{t,H} + \dot{W}_{t,L} \ \text{[W]} \qquad (41)$$

Based on the quantified fundamental formula on Heart-Lungs interaction, the performance of the Cardio-Pulmonary System, namely the total Mechanical Work, $W_{t,CPS}$, and the total Power $\dot{W}_{t,CPS}$ can be expressed as function of only one Frequency (Speed), F_H or F_L.

The Entropy Source for the Heart is calculated as:

$$\dot{S}_H = \frac{\dot{Q}_{irr,H}}{T_{blood}} = \frac{\dot{W}_{t,H}}{T_{blood}} \ \text{[W/K]} \qquad (42)$$

where T_{blood} is the blood Temperature [K]. In humans the blood Temperature varies between 35°C in the skin capillaries and 39 °C in the internal organs of the abdomen [17, 18], $Q_{irr,H}$ is the heat caused by the friction in the heart and blood vessels equal with the power consumed by the heart, $W_{t,H}$.

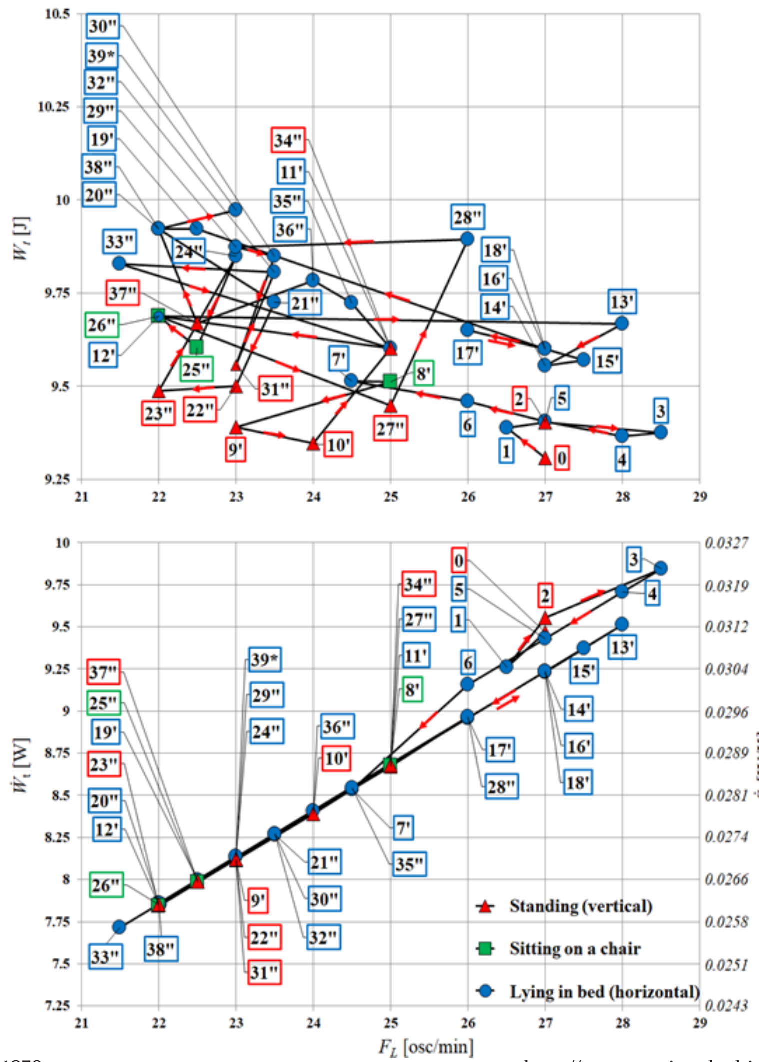

Fig. 3. The diagrams of total Mechanical Work, $W_t = f(F_L)$, total Power $\dot{W}_t = f(F_L)$ and the total Entropy Source $\dot{S}_t$[W/K] (for SP - Stoian Petrescu)

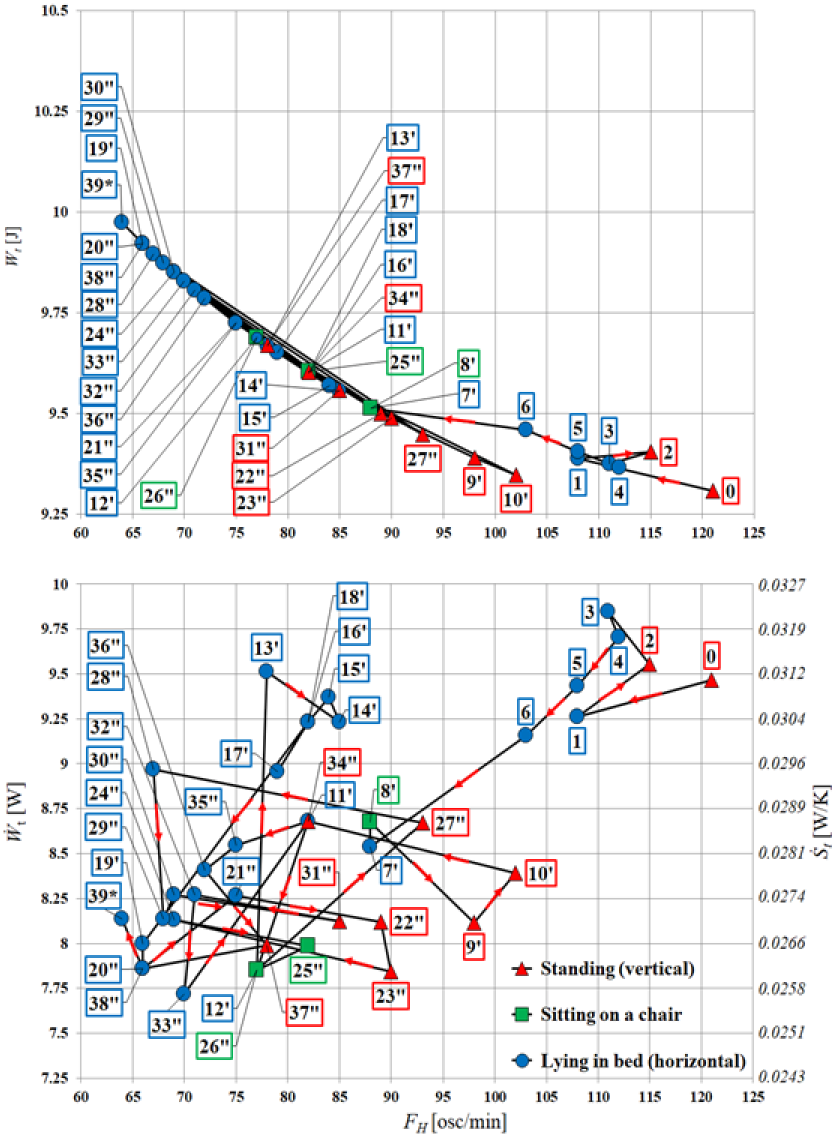

Fig. 4. The diagrams of the total Mechanical Work, $W_t=f(F_H)$, total Power $\dot{W}_t=f(F_H)$ and the total Entropy Source $\dot{S}_t$ [W/K] (for SP).

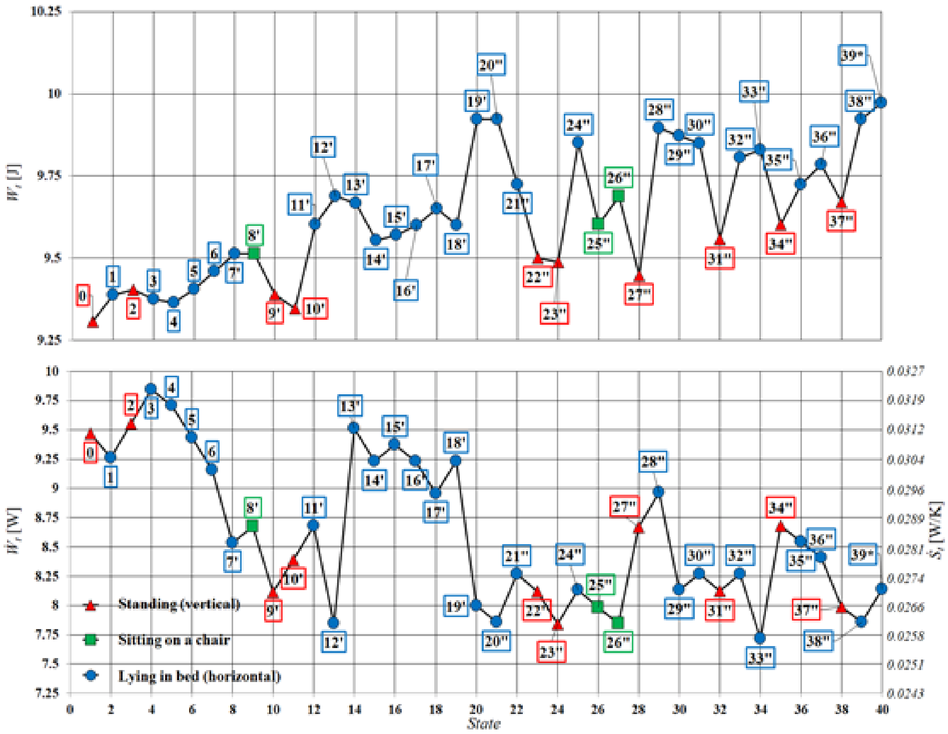

Fig. 5. The diagrams of the total Mechanical Work, $W_t=f$(state), total Power $\dot{W}_t=f$(state) and the total Source of Entropy $\dot{S}_t$[W/K] (for SP).

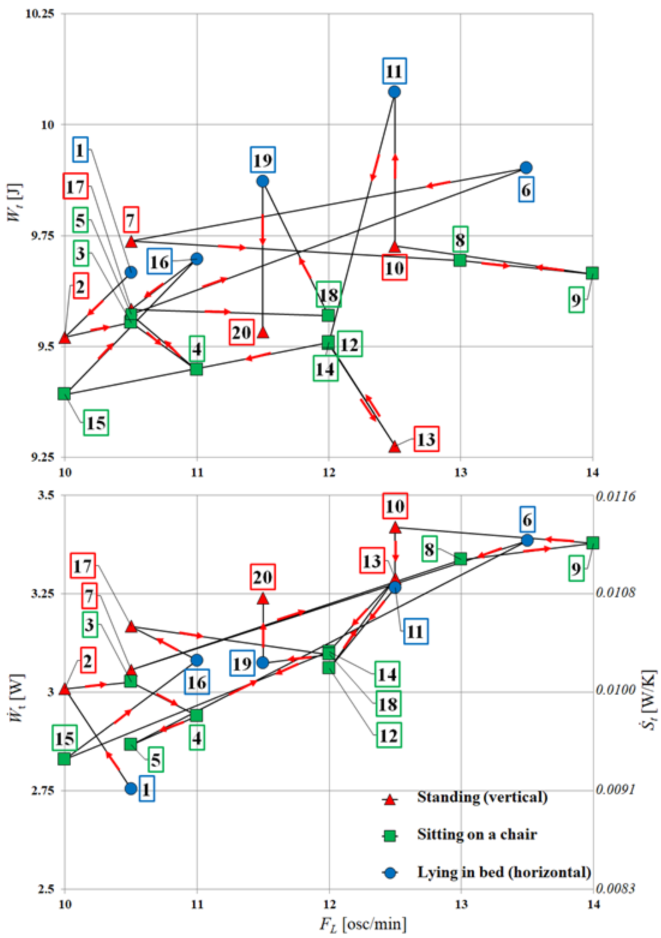

Fig. 6. The diagrams of total Mechanical Work of the Cardio-Pulmonary System, $W_t=f(F_L)$, total Power $\dot{W}_t=f(F_L)$ and the total Entropy Source $\dot{S}_t$ [W/K] (for BB-Bogdan Borcila).

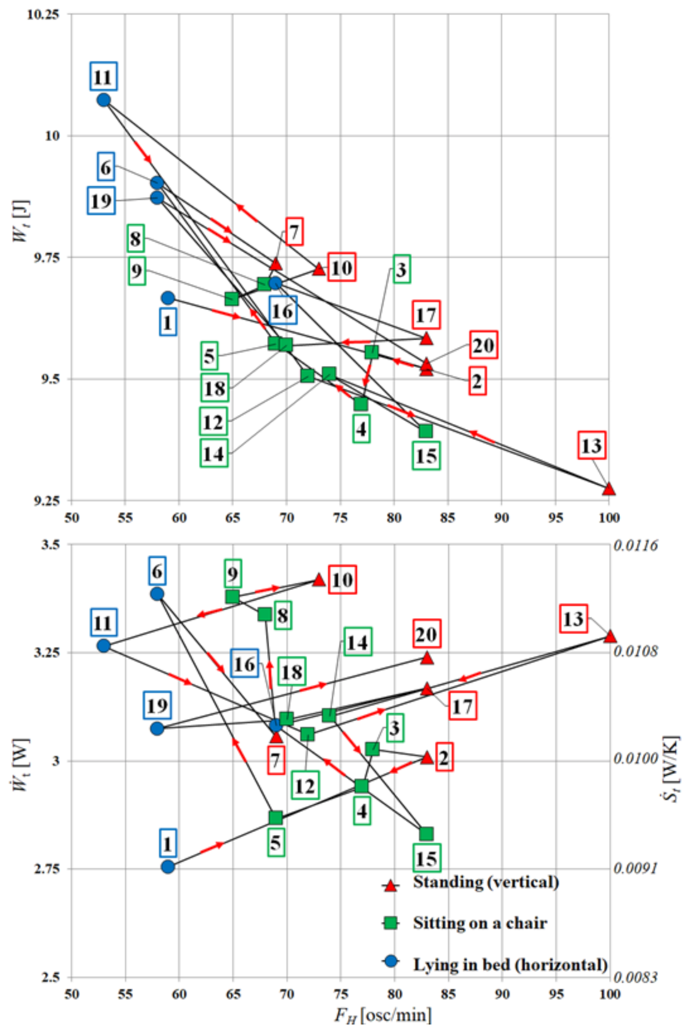

Fig. 7.The diagrams of the total Mechanical Work, $W_t=f(F_H)$ of the CPS, the total Power $\dot{W}_t=f(F_H)$ and the total Entropy Source $\dot{S}_t$ [W/K] (for BB).

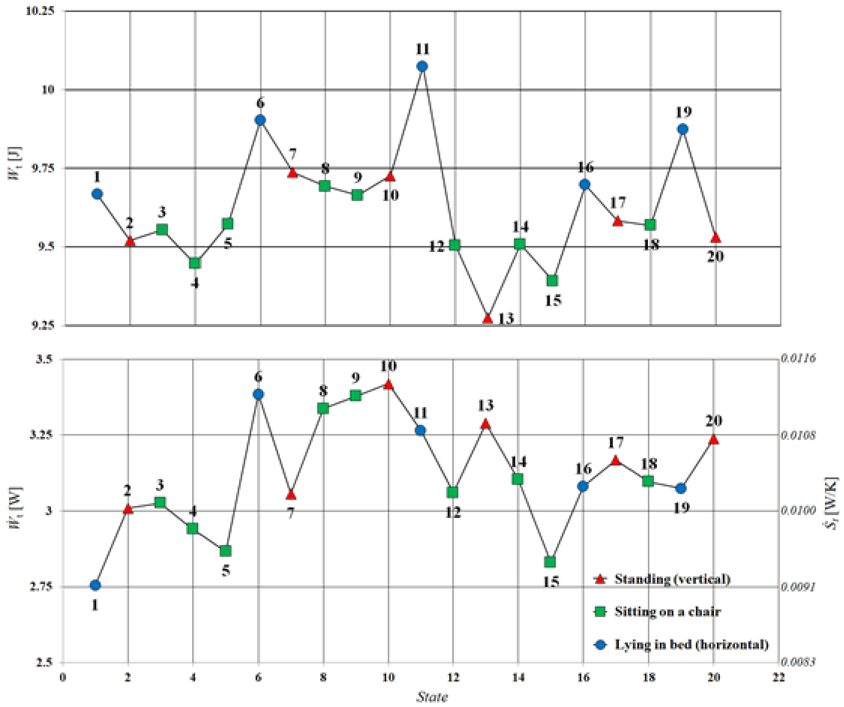

Fig. 8. The diagrams of the total Mechanical Work, W_t=f(state), total Power $\dot{W}_t$=*f*(state) and the total Source of Entropy $\dot{S}_t$ [W/K](for BB).

The Source of Entropy for the Lungs is determined with the relation:

$$\dot{S}_L = \frac{\dot{Q}_{irr,L}}{T_{air}} = \frac{\dot{W}_{t,L}}{T_{air}} \text{ [W/K]} \qquad (43)$$

$\dot{Q}_{irr,L}$ is the heat caused by the friction in the lungs equal with the power consumed by the lungs $\dot{W}_{t,L}$.

The total source of entropy for the CPS is:

$$\dot{S}_t = \dot{S}_H + \dot{S}_L \qquad (44)$$

In the respiratory region of the nasal cavity, the vascular network from mucous tunic and the venous cavernous plexus of the cornets, that are well developed at the lower level of cornet and the anterior inferior portion of the membranous nasal septum, create favorable conditions for inspiratory air heating up to 32÷34 °C·[17, 18].

Applying the computation scheme for determining the total Cardio-Pulmonary System Power in two studied cases

In the paper were used the parameters measured by two persons: Stoian Petrescu (SP, 78 years old) and Bogdan Borcila (BB, 29 years old).

In all the figures, the triangle represents stationary states (standing vertical), square represents stationary (states sitting on a chair), circle represents stationary states (lying in bed).

In figures 3-5 illustrate the diagrams of the Mechanical Work and the total cardio-pulmonary Power as functions of the two fundamental parameters, F_L, F_H - measured in different positions during 3 days while the person SP was ill of the flu - and the State Numbers 0, 1, 2, ..., 39) between which various elementary Processes are emphasized.

The analysis of the variation of the two parameters of the Cardio-Pulmonary System $(\dot{W}_{t,CPS}, W_{t,CPS})$ at the successive passage from one elementary Process to another during the 3 days when the person was suffering of the flu shows that she had higher Power consumption in the first two days of the disease when the flu had high intensity while the Mechanical Work was almost constant.

The analysis of the Heart oscillation of the Cardio-Pulmonary System in the successive passage from one elementary Process to another during the 3 days when the person was suffering of the flu had higher Power consumption in the first two days of the disease when the flu had high intensity. On the third and fourth day, with the gradual healing of influenza, the total Power values of the Cardio-Pulmonary System (CPS) went down to normal. Regarding the total Mechanical Work of CPS, it was found that its variation was also reduced.

Thus, the total Mechanical Work for the person SP Cardio-Pulmonary System varies between: 9.31 and 9.40 J (on the first day), 9.35 and 9.92 J (the next day), 9.45 and 9.92 J (third day), 9.97 J (fourth day, determined for a state). The total Power oscillates between the following values: 9.16 - 9.85 W (on the first day), 7.85 - 9.51 W (the next day), 7.72 - 8.97 W (third day), 8.14 W (fourth day).

Therefore, it is noted that when SP was very ill with flu, the variations of the Cardio-Pulmonary System Power were higher, and from the second part of the third day they stabilized and returned to the limits before the illness, while the Mechanical Work had insignificant oscillations.

The study of the diagrams from figures 3-5 reveals a tendency for a increase in total Cardio-Pulmonary System Power for SP (about 22%), with increasing of the Heart, F_H, and Lungs Frequencies, F_L. In the case of Mechanical Work, it decreases as the Heart and Lungs Frequencies increase.

For the person SP, the total Entropy Source for the Cardio-Pulmonary System, $\dot{S}_t$, has values between 0.0153 and 0.0191 W/K. At the onset of flu (State Number 0 from figures 3-5), the *Entropy Source*, $\dot{S}_t$, was at the highest level (0.0191 W/K) and as the person has healed, it dropped to the normal values (0.0153 W/K) [19-25].

Based on eqs. (40) and (41), calculation was made for total values of Mechanical Work and Power of the Cardio-Pulmonary System of person BB (Bogdan Borcila) as a function of a single Speed (the Frequency of Lungs or Heart, F_L or F_H).

In figures 6-8 we represented the diagrams of the Mechanical Work and the total Power for the Cardio-Pulmonary System of the person BB . The two performance parameters were written as function of the Frequencies F_L, F_H, and the Stationary State Numbers (1, 2, 3, ..., 20) in which take place the various elementary and complex Processes, for example changing the position from a bed to a chair, in the complex process of eating, working on the computer, etc.

The comparative study of the diagrams showing the variations in Mechanical Work and the total Cardio-Pulmonary System Power, when passing successively from one elementary or complex process to another reveals a normal Power consumption depending on the different States.

Thus, in the upright position, the muscular system of body - the striated muscles (skeletal muscles); the smooth muscles (which make up the viscera, the blood vessels and the skin); Heart muscle (myocardium) - has intense activity and hence, an average consumption until high values of Mechanical Work and Power [27, 28] (the Stationary Quantum States: 2, 7, 10, 13, 17 and 20).

In the lying position, the total Mechanical Work values are medium and large, because the center of gravity of the body oscillates vertically in the gravitational field and therefore the body exerts an additional effort during breathing (the Stationary States: 1, 6, 11, 16, 19).

The Power consumed by the Cardio-Pulmonary System in this case, when the body is relaxed, also has average and above average values in most Stationary Quantum States, except for the initial State 1.

At the same time, the diagrams illustrating the variation in Mechanical Work and total Power in stationary conditions corresponding to the seating position indicate that their values are predominantly the lowest (the Stationary States: 3, 4, 5, 12, 14, 15, 18), with the exception of States 8 and 9 in which BB has performed activities with a higher degree of mental effort at the computer. The total Mechanical Work for the BB person's Cardio-Pulmonary System varies between 9.28 and 10.07 J, and the total Power has values ranging from 2.75 to 3.42 W, depending on the body's effort in the different processes elementary and complex.

Also, the study of the diagrams in figures 6-8 reveals the trend of high increase in total Cardio-Pulmonary System of BB, with increasing of the Heart, F_H, and Lungs, F_L, Frequencies. In the case of the total Mechanical Work of CPS, the values have a decreasing trend with the increase of the Lungs Frequency.

Analyzing the distribution of the total Mechanical Work of the Cardio-Pulmonary System between the two components, we find that $W_{t,L}$ has the highest values (about 90%), while $W_{t,H}$ is much lower. In the case of the total Power of CPS, $\dot{W}_{t,h}$, and $W_{t,h}$ are approximately equal.

It results that the difference is due to the greater value of Mechanical Work of the respiratory muscles that increase the dimensions of the chest cavity and of the contraction of the diaphragm muscle area, for ensuring normal breathing [18-20, 27].

The total Entropy Source of the Cardio-Pulmonary System, S_t, for the person BB, is between 0.0089 and 0.0110 W/K.

The analysis of the performance parameters of CPS for SP and BB shows significant differences between them. Thus, the total power of CPS, for SP varies between 9.85-7.72 W and the mechanical work from 9.92 to 9.31 J. For BB, the two parameters have the following values: $\dot{W}_{t,CPS}$ = 2.75-3.42 W and $W_{t,CPS}$ = 9.28 - 10.07 J.

The relatively large differences between the parameters of the two persons could be explained based on the F_H, and F_L Frequencies, which are much lower for BB compared to SP - $F_{L,aver}$ = 11.5 osc / min and $F_{H,aver}$ = 72 osc / min (for BB) and $F_{L,aver}$ = 24.5 osc / min and $F_{H,aver}$ = 84 osc / min (for SP). Furthermore, the high power consumed by CPS of the SP can be caused by the processes of homeostasis that help maintain the internal environment of the human body within normal limits when it is affected by stressful conditions such as illness, heat, pain, etc. [18-20, 27].

Conclusions

The new *Scheme of computation of Mechanical Work and Power of the Heart and Lungs* allows the study of the variation of the two parameters of the Heart and Lungs in Stationary Quantum States, based on the values calculated with the analytical formulas discovered that where customized to each person. Thea analytical expressions of total Mechanical Work and Power of the Cardio-Pulmonary System were grounded as functions of the measured parameters (F_H and F_L), the maximum systolic pressure and person's body mass. On the basis of *the quantified fundamental formula on Heart-Lungs interaction*, the two performance parameters of the Cardio-Pulmonary System, total Mechanical $W_{t,CPS}$, and total Power, $\dot{W}_{t,CPS}$ can be expressed as single Frequency functions, F_H or F_L.

The calculation scheme has been verified as the results obtained by applying it are very close to those in the literature [19-25].

The diagrams of the Mechanical Work and the total Power presented above for the Cardio-Pulmonary System provide very important information on Heart-Lungs interaction for each person (SP and BB). They also emphasize the conclusion that each person is different from each other in terms of Heart-Lungs interactions on the one hand and the Cardio-Pulmonary System - the whole body on the other. Such information could be particularly useful if a person needs a pacemaker or even an artificial Heart. The two devices could now be designed based on personalized data using diagrams obtained by any person [7-15] before they needed such artificial devices to save their lives.

References

1. PETRESCU, S., COSTEA, M., et al., Development of Thermodynamics with Finite Speed and Direct Method, Bucharest, Romania. AGIR, 2011.

2. PETRESCU, S., COSTEA, M., FEIDT, M., GANEA, I., BORIARU, N., Advanced Thermodynamics of Irreversible Processes with Finite Speed and Finite Dimensions, Bucharest, Romania, AGIR, 2015.

3. PETRESCU, S., COSTEA, M., TIMOFAN, L., PETRESCU, V., Means for Qualitative and Quantitative Description of the Cardio-Pulmonary System Operation within Irreversible Thermodynamics with Finite Speed, Proceedings of ASTR Conference, Sibiu, Romania, 2014.

4. PETRESCU, S., PETRESCU, V., COSTEA, M., TIMOFAN, L., DANES, S., BOTEZ, G., Discovery of Quantum Numbers In the Cardio-Pulmonary Interaction Studied in Thermodynamics with Finite Speed, Proceedings of ASTR Conference, Sibiu, Romania, 2014.

5. PETRESCU, S., COSTEA, M., PETRESCU, A.S., PETRESCU, V., From Thermodynamics with Finite Speed towards Biological Quantum Thermodynamics with Finite Speed, Proceedings of the National Conference of Thermodynamics NACOT'15, Iasi, Romania, 2015.

6. PETRESCU, S., COSTEA, M., PETRESCU, V., BOLOHAN, R., BORIARU, N., PETRESCU, A.S., BORCILA, B., Stationary Quantum States in Cardio-Pulmonary System, Proceedings of ASTR Conference, Galati, Romania, 2015.

7. PETRESCU, S., COSTEA, M., PETRESCU, A.S., PETRESCU, V., BORIARU, N., BOLOHAN, R., BORCILA, B., Processes with Quantum Jumps in the Cardio-Pulmonary System, Proceedings of ASTR Conference, Galati, 2015.

8. PETRESCU, S., BOLOHAN, R., PETRESCU, V., BORCILA, B., COSTEA, M., Diagrams Describing Stationary States and Processes in Cardio-Pulmonary System, Proceedings of ASTR Conference, Targu-Mures, 2016.

9. PETRESCU, S., PETRESCU, V., BOLOHAN, R., COSTEA, M., BORCILA, B., Complete Circadian Cycle of Cardio-Pulmonary System Studied in

Quantum Biological Thermodynamics with Finite Speed, Proceedings of ASTR Conference, Targu-Mures, 2016.
10. PETRESCU, S., PETRESCU, V., BOLOHAN, R., BORCILA, B., COSTEA, M., Quantum Biological Thermodynamics with Finite Speed of the cardio-respiratory system as a new extension of Thermodynamics with Finite Speed, COFRET 2016 June 29-30, Proceedings of COFRET'16, Bucharest, Romania, 2016.
11. PETRESCU, S., PETRESCU, V., BOLOHAN, R., BORCILA, B., COSTEA, M., DANES, S., FEIDT, M., BOTEZ, G., HUMINIC, G., HUMINIC, A., BORIARU, N., POPESCU, G., MANITIU, N., DUMITRASCU, N., PANAITE, E., LOZONSCHI, T., GHEORGHIAN, A., How different we are in terms of Heart-Lung interaction: discovery and description in Quantum Biological Thermodynamics with Finite Speed, COFRET 2016 June 29-30, Proceedings of COFRET'16, Bucharest, Romania, 2016.
12. PETRESCU, S., BORCILA, B., PETRESCU, V., COSTEA, M., BOLOHAN, R., et. al, What is quantum biological thermodynamics with finite speed of the cardio-pulmonary system: a discovery or an invention, Constructal Law &Second Law Conference, Romanian Academy, Bucharest, 2017.
13. BORCILA, B., PETRESCU, S., COSTEA, M., BOLOHAN, R., PETRESCU, V. and BOTEZ, G.,Effect of flue on stationary states and processes in the cardio-pulmonary system described in Quantum Biological Thermodynamics with Finite Speed, The 8 th International Conference on Advanced Concepts in Mechanical Engineering, ACME 2018, June 7 - 8, Iasi, Romania.
14. BORCILA, B., PETRESCU, S., COSTEA, M., BOLOHAN, R., PETRESCU, V., and BOTEZ, G., Effect of flue on Stationary States and Processes in the Cardio-Pulmonary System described in Quantum Biological Thermodynamics with Finite Speed, ACME, 2018.
15. PETRESCU, S., BORCILA ,B., COSTEA, M., PETRESCU, V., BOLOHAN, R., Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System: I- Fundamental Concepts, Equations and Diagrams, Rev. Chim (Bucharest), **70**, no. 5, 2019, p. 1561
16. CISMAS-PRUTEANU, P., MATEI, D., ZAHA, D., NEGREAN, R., POP, A., Fiziologie - Note de curs pentru studentii colegiilor medicale, Universitatea din Oradea, Facultatea de Medicina si Farmacie, Oradea, 2010.
17. POP, M., SAS, I., Fiziologie animala si umana, Ed. Universitatii din Oradea, 2005.
18. FLONTA, M. L., MARCU-LAPADAT, M., RISTOIU, V., Notiuni de anatomie si fiziologie, Ed. Universitatii din Bucuresti, 2011.
19. STUART, I. F., Human Physiology, Mc Graw Hill, Twelfth Edition, ISBN 978-0-07-337811-4, 2011.
20. MOLNAR, A.M. (traducere) Atlas de fiziologie umana, ISBN 978-973-30-2837-6, EDP Bucuresti, 2011.
21. GINGHINA, C., POPESCU, B. A., JURCU R., Esentialul în ecocardiografie, ISBN 978-606-8470-02-3, Editura Medicala Antaeus, Bucuresti, 2013.
22. CUTNELL J., JOHNSON K., Physics, Fourth Edition, Wiley, 1998.
23. KRAMER, G.H., CAPELLO, K., BEARRS, B., LAUZON, A., NORMANDEAU, L., Linear dimensions and volumes of human lungs obtained from CT images, Health Phys,102(4):378-83, 2012.
24. MACKEY D. C., WASNICK J. D., Morgan & Mikhail's Clinical Anesthesiology Fifth Edition, John F. Butterworth IV, MD, MPH, by McGraw-Hill Education, LLC., 2013.
25. FELDSCHUH J., ENSON, Y., Prediction of the Normal Blood Volume Relation of Blood Volume to Body Habitus M.D., 56:605-612, doi: 10.1161/01.CIR.56.4.605, Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231, vol. 56, no. 4, 1977.
26. PADUREAN, I., Mecanica fluidelor si actionari hidraulice, Editia a 2-a, revazuta si adaugita, Editura Eurostampa, Timisoara, 2012.
27. KENT, M., Van De Graff, Concepts of Humans Anatomy and Physiology, fourth edition, University of Utah, Stuart Ira Fox, Pirce College, Wm. C. Brawn Communications, Inc. (Columbus Ohio: Published by McGraw-Hill Higher Education), 1995.
28. ARTHUR, C., GUYTON, J., HALL, E., Textbook of Medical physiology, Twelfth edition, International edition: 978-0-8089-2400-5, 2011.

Manuscript received: 25.09.2018