System and Process of Electric Energy Cogeration for Data Centers Environment Servers

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ABSTRACT
Reducing part of the energy consumption generated by servers in Data Centers, through the cogeneration, establishing a new application of clean and renewable energy generation. Much of the electrical consumption within Data Centers occurs above all due to the need to cool these rooms. It is intended therefore to present a change of this model by harnessing this heat, generating energy and for this reducing the consumption of the electricity grid. In addition, it is presented a mechanism which allows controlling the temperature of the processor, using heat sink and motor Stirling. The research is theoretical in essence and is applied based on the collection of heat by convection by the coolant normally used for the liquid cooling. Besides it will be numerically verified that the temperature difference between the heat generated by the electronic components and the refrigerant can be used as the working force of the Stirling engine which in its turn is connected to an electric generator. This work does not aim to exhaust the possibilities of the research on its aspect, rather it aims to disseminate knowledge and introduce the theme.

General Terms
Green IT, Green Energy, Cogeneration for Datacenters, Sustainability.

Nomenclature
A_{st} - Cross-sectional area of the channel.

c - Characteristic coefficient of the material.

Cp - Thermal capacity at constant pressure [J / kg K].

Dh - Hydraulic diameter.

h - Coefficient of heat transfer by convection.

I - Current of the respective bus.

kc - Thermal conductivity of the material.

KPa – Unit of measurement for atmospheric pressure.

LTD – Low temperature Stirling engine.

m - Mass of material measured in kg.

Nb - Number Beale.

Ns/ m^2 - Newtonseconds per square meter.

Nu – Number Nusselt.

P - Power supply power.

POT – Power sum multiplied by frequency.

Pr - Prandtl number.

Q - Quantity of thermal energy in Joules [J].

Re – Reynolds number.

T1f - Cold fluid inlet temperature [°C].

T1q - Hot fluid inlet temperature [°C].

T2f - Cold fluid outlet temperature [°C].

T2q - Hot fluid outlet temperature [°C].

V - Consumption of the respective component measured in volts.

W – Power.

α - Thermal diffusivity [m^2 / s].

Δt - Variation of time in 'N' seconds.

$\Delta\theta$ - Temperature variation of material measured in Kelvin.

ν - Kinematic viscosity [m^2 / s].

ρ - Volumetric mass [kg / m^3].

Keywords
Energy Consumption, Data Centers, Heat Sink, Motor Stirling, Electric Generator.

1. INTRODUCTION
The portability of mobile devices has intensified to the point of allowing users to perform various personal activities on their smartphones. It must be said that much of the previously

developed activities just in front of the computer, such as paying invoices for accounts, accessing publishers and spreadsheets can now be carried out online by means of smartphones. This decrease of the hardware resources does not mean that the processing of the information has become smaller [1].

Cloud computing is an option to use the traditional desktop through the use of huge Data Centers that operationalize information through robust hardware systems coupled with high-speed computer networks. Moreover, the availability of online systems is also possible due to the application of quality certifications that validate the product guarantee that users use [2].

TIER Certification is used to measure the level of infrastructure of a site for the operation of a data processing center (CPD) [3]. The application of this certification is important since if these large data centers cease to function due to lack of electricity, all customers connected to it would be harmed.

In TIER Certification, there are two (out of a total of four) classifications that are TIER 3 and TIER 4, which allow to achieve a 99.982% and 99.995% Data Center operation availability, respectively [4].

The availability of operation is guaranteed through a double input of electrical energy, which is usually composed of the use of the electric power of the concessionaire and of the Group Generator Motor (GMG) diesel. Many companies, instead of spending on the purchase of diesel, prefer to use electric cogeneration as the second energy input. In this respect, sustainable companies such as Apple and Google use photovoltaic and wind power, respectively [5].

Based on the above introductory information, this study proposes a new way of obtaining cogeneration energy for large data processing centers.

2. METHODOLOGY

The data for verification were obtained in installation manuals of the Data Center infrastructure. As it is, with respect to the secondary cooling water cycle, in the case of racks [6] of IBM blade servers, they have a duct measuring from 10 to 14 mm in diameter. On the other hand, in the primary water cooling cycle, in the Data Center itself, according to [7], the duct measures from 150 to 600 mm in diameter. In addition, [8] presented a detailed model incorporating the first law of thermodynamics, as well as the calculation of geometric parameters, mass flow and leaks.

Besides the geometric characteristics, it was also necessary to know the thermal characteristics of the cooling systems. Once more, the data provided by manufacturers of data center equipment was obtained. For instance, in the case of the IBM zEC12 mainframe, the technical manual known as [9], provides information that in the idle state of the processor the fluid inlet temperature is -40 ° C and the outlet temperature is 60 ° C . Following this procedure as a model, the other temperature data were obtained for the primary and secondary cycle.

Finally, the methods and techniques that were used in the preparation of the work are:

• Deductive method: it comes from the study of the general for the individual;

• Qualitative research: bibliographical or documentary.

2.1 Thermal Process

First, the thermal cooling process consists of pumping refrigerated fluid to the electronic components, by being these processing chips video cards, chipsets, among others. This mechanical piping system consumes a lot of energy by means of pumps and fans to carry cold water or air, and long-distance transport can result in appreciable loss [10]. As a solution to this problem, water-cooled Data Centers have partitioned cooling cycles.

Pumping that occurs externally to the Data Center is called the primary cooling cycle, and the pumping occurring internally to the Data Center is called the secondary cooling cycle. After completing the cooling circuit inside servers, the fluid returns heated to be refrigerated again as it passes through these two cycles. Three configurations of micro scalar heat transfer were found, that is, that uses micro channel and a macro scalar cooling configuration, which uses a large diameter duct.

The efficiency of Data Center cooling systems can be improved by eliminating or reducing long-distance transport. Some previous studies have found several solutions to such problems, such as the use of back door refrigerators [11], ceiling refrigerators [12] and fans controlled by frequency inverters [13].

Other fundamental equipment present in the system is the suction pump, [14] after which it allows the forced displacement of the fluid to pass through mini channels, micro channels and normal channels [15]. The suction capacity of a water pump is determined from the specific design of the Data Center, however, standardized and reference values are reported by the companies that supply the equipment.

2.2 Nature of the Fluid

The nature of the fluid is not only water but water mixed with ethylene glycol. This substance has the function of increasing the boiling temperature and lowering the freezing temperature in the mixture [16].

The fluidic characteristics used in the verification of this work were obtained through the work of dissertation [17].

2.3 Applications

The four possibilities investigated are shown through figures created in AutoCAD [18], and they have, in addition to the dimensioned experiment [19], also the integrated parts, as pre-existing equipment in the environments. Follow below:

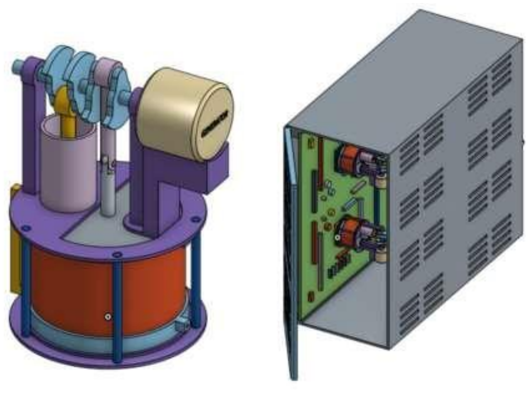

Figure 1 - Application to Tower Server in secondary cycle.

Figure 2 - Application for Rack Server in secondary cycle.

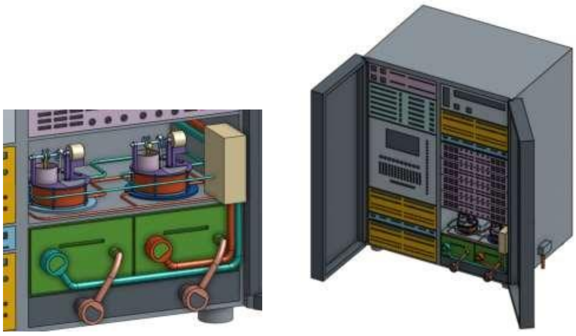

Figure 3 - Application to Mainframe Server in secondary cycle.

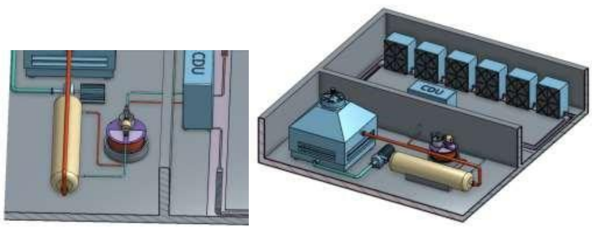

Figure 4 - Application to Datacenter in primary cycle.

2.4 Restrictions

For the application of the calculations shown below, it was guaranteed that the value of thermal energy in unit of power was the closest to the real.

The formula, represented by the Law of Joule, which uses the electric consumption of the electronic components for calculating, as it follows (Eq. 2.1):

$$P = V \times I \tag{2.1}$$

For the power input data in the tower server mechanism, power values of the thermal processor design, known as TDP, were used, in that case the percentage of 20 to 30% was applied for thermal energy generation of the total consumption, of the value consumed by the transistors in the processors.

Regarding the mechanism for rack servers, as it is a cooling circuit, that is, they cover other electronic components, in addition to the processors themselves, the percentages of actual power and cooling efficiency were applied, on the recording power of the power supply for rack-mounted blade servers.

For mainframes, the verification was mainly based on the minimum value of the consumption of the processing book, disregarding for calculation other values of the cooling circuit that should be added for the respective consumption and power margin.

Concerning to the primary cooling cycle, corresponding to the Data Center itself, it is considered that it cools at turning the fluid which is coming from the secondary cycle, just of the three equipment discussed in the previous paragraphs. An average power was made with the values of the mechanisms, based on the manual of physical planning and the preparation of the site in power systems [20] and applied to the configuration of the Data Center.

It was determined that for each mechanism discussed it would be used only one equipment, such as the power input per application of the environment, followed by five checks, for example a tower server, a blade server, a mainframe and the Data Center itself in the cycle, followed by the five checks for each.

2.5 Validation of Thermal Process Data

First, it is necessary to validate the data of the thermal process in order to apply the following three formulas (Eq. 2.2):

$$Qhot = Qcold$$
$$Qhot = m.\ Cp.\ \Delta Thot \tag{2.2}$$
$$Qcold = m.\ Cp.\ \Delta Tcold$$

To know the heat flux transferred by the contact area of the processor with the heat sink and time, by the following equation (Eq. 2.3):

$$\text{Flow} = \frac{J}{\text{cm}^2 . \text{s}} \tag{2.3}$$

2.6 Calculation of the Thermal Exchange Surface

First, we calculate the logarithmic mean temperature difference (DTML) based on the heat sink input and output temperatures (Eq. 2.4):

$$DTML = \frac{(T1f - T2q) - (T2f - T1q)}{In(T1f - T2q) - In(T2f - T1q)} \tag{2.4}$$

With the calculated values of energy and DTML, we calculate the thermal exchange surface with the following formula (Eq. 2.5):

$$Q = K . A . DTML \tag{2.5}$$

2.7 Calculation of Coefficient K and Embedding

The heat transfer coefficient K of a heat exchanger is calculated by the following formula (Eq. 2.6):

$$\frac{1}{Kembedding} = \frac{1}{h1} + \frac{1}{h2} + \frac{x}{k} + Rembedding \tag{2.6}$$

First, we find the hydraulic diameter of the duct used in the experiment, by the equation (Eq. 2.7):

$$Dh = \frac{4\, A_{st}}{P_{\ w}} \tag{2.7}$$

Second, it is possible to find the Reynolds number to identify and characterize the type of flow that the heatsink possesses, which, depending on the value generated, can be in a laminar or turbulent stand (Eq. 2.8).

$$Re = \frac{pVD_h}{\mu} \tag{2.8}$$

Third it is related to the transport property of the fluid and for this purpose the Prandtl number provides a measure of efficiency relative to the movement and also transport energy in the hydrodynamic and thermal layers, given by the equation (Eq. 2.9):

$$Pr = \frac{Cp\,\mu}{K} = \frac{\mu/p}{K/pc_p} = \frac{V}{\alpha} \qquad (2.9)$$

Physically, the Prandtl number represents:

$$\frac{Diffusion\ of\ the\ amount\ of\ movement\ (velocity)}{Heat\ diffusion\ (temperature)}$$

The dimensionless number of Nusselt, Nu, is given by the equation (Eq. 2.10):

$$Nu = \frac{h\,Dh}{k} \qquad (2.10)$$

To calculate the Nusselt number in flows and in the transition region and turbulent, for mini channel and micro channel, [21] it is suggested the use of such equations Eq. (2.11) and Eq. (2.12):

For 0,5 < Pr < 1,5

$$Nu = 0{,}0214\,[1{,}0 + (Dh)^{\frac{2}{3}}][Re^{0{,}8} - 100]Pr^{0{,}4} \qquad (2.11)$$

For 1,5 < Pr < 500

$$Nu = 0{,}012\left[1{,}0 + (Dh)^{\frac{2}{3}}\right][Re^{0{,}87} - 280]Pr^{0{,}4} \qquad (2.12)$$

The attainment range of the heat transfer coefficient allows finding the required area for thermal exchange and therefore the dimension of the heatsink.

2.8 Calculation of Heat Sink Load Loss

A moving fluid suffers from energy losses due to the friction in the walls (regular loss of load) or setbacks (singular loss of load) such as curves and baffles. The loss of energy, expressed in pressure drop (ΔP), must be compensated to allow the fluid to continue moving. When a heatsink is designed, its load loss can be calculated for different correlations determined by the characteristics of the thermal exchange surface. Steps 2 and 3, shown in the flowchart below which are performed by interdependence and interactions, until an optimal value is estimated:

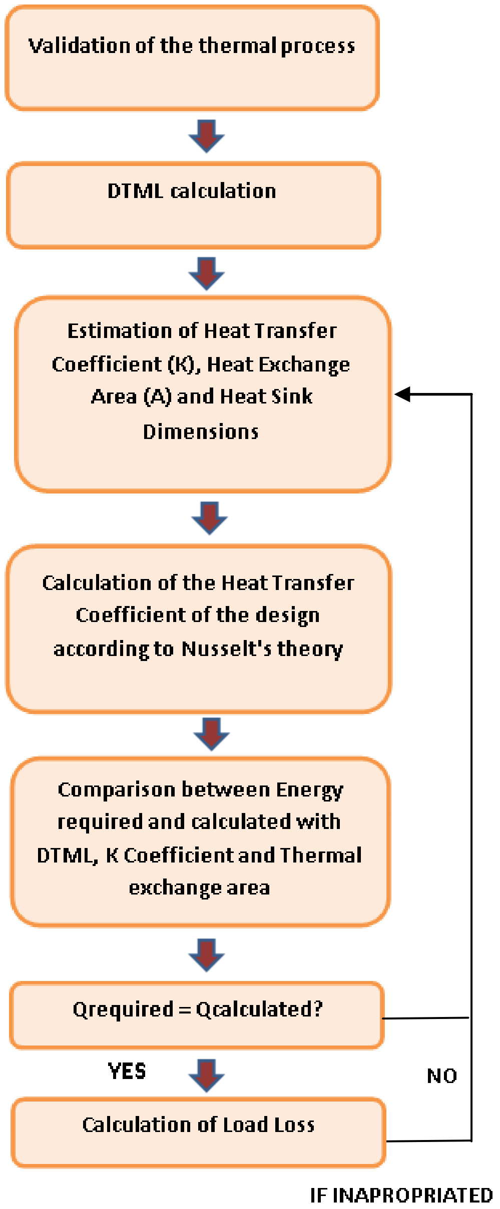

Figure 5 - Flowchart to estimate an optimal value.

2.9 Heat Sink Efficiency and Efficiency

Considering that there is no radiation loss, the efficiency of the heat sink equals 1. The efficiency (yield) corresponds to the following formula:

$$\frac{Energy\ received}{Energy\ available}$$

Under real conditions, it is impossible to obtain a yield of 100%. The efficiency of the sink depends on the amount of energy to be transferred and the temperatures of the application.

2.10 Thermal Analysis Modeling for the Stirling Engine

The Schmidt Theory [22] starts from existing geometries, from which one can obtain an approximation of the operation of the Stirling engine theoretically. That is why it does not consist of calculations to perform an inverse process.

Therefore, before accomplishing this theory, one must establish the characteristics of the mechanism that is sought.

The power output modeling of the Stirling engine can be given using the Beale number. The Beale number is given by the equation allowing its operation which is presented below (Eq. 2.13):

$$W = N_b \; P_{med} V_b \;\; f \qquad (2.13)$$

In this way, it is possible to adjust the volume swept by the piston of the desired power, the medium pressure and the frequency. This sweep volume corresponds to the expansion piston.

Therefore, the swept volume is obtained by the equation (Eq. 2.14):

$$V_b = \frac{W}{N_b \; P_{med} f} \qquad (2.14)$$

As the two pistons operate at different temperatures and at different pressures, but with constant mass, their volumes are not the same. It is possible to relate the piston sweep volume of compression and expansion, once the gas states in both are known. This is achieved from the gas density in each zone.

HIRATA (2017) recognizes this by means of the following equations (Eqs. 2.15 and 2.16):

$$p_1 V_1 = p_2 V_2 \qquad (2.15)$$

$$\frac{V_2}{V_1} = \frac{p_1}{p_2} \qquad (2.16)$$

Since the volume swept by each piston is known, it must be related to the position or its area to know its diameter. Therefore, we obtain the equation (Eq. 2.17):

$$X_b = d_{pe} \qquad (2.17)$$

As a result, by slightly modifying the sweep volume expression (Eq. 2.18), we obtain:

$$V_b = X_b A = \frac{X_b A \pi D^2 pe}{4} = \frac{W}{N_b \; P_{med} f} \qquad (2.18)$$

Then, by cleaning the diameter, we conclude that:

$$d_{pi} = \frac{\sqrt[3]{4W}}{N_b \; P_{med} f} = \frac{\sqrt[3]{4W}}{\pi} \qquad (2.19)$$

Thus, the diameter of the piston is obtained from its volume and consequently the sweep distance traveled by the piston is also known. The same diameter calculation is carried out with both pistons.

Then this stroke of the piston is Xe = dpe.

The length of the connecting rod and the radius of the crank are expressed in the equation (Eq. 2.20):

$$L_b = 2 * X_e \qquad (2.20)$$

$$r_m = L_b / 4$$

2.11 Modeling the Output Power for the Stirling Engine

Once having the sizing, it is possible to calculate the work and power of the Stirling engine. In order to have the work defined for each zone, expansion and compression, such as (Eqs. 2.22 and 2.23):

$$W_e = \frac{P_{med} \, V_{be} \pi c \, \sin(a)}{1 + \sqrt{1 - c^2}} \qquad (2.22)$$

$$W_c = \frac{P_{med} \, V_{be} \pi c t \, \sin(a)}{1 + \sqrt{1 - c^2}} \qquad (2.23)$$

Total work is the sum of jobs (Eq. 2.24):

$$W = W_e + W_c \qquad (2.24)$$

The power is obtained directly by the work produced and the speed of rotation (Eq. 2.25).

$$Pot = Pot_e + Pot_c = W_e \, n + W_c \, n \qquad (2.25)$$

2.12 Transfer of Mechanical Energy to Electrical Energy

As the ideal thermal yield of the Stirling cycle is the same as that of Carnot, and the methodology used has provided the mechanisms to obtain the temperatures of the high and low thermal equipments, we can obtain their value (Eq. 2.26).

$$P_{mec} = \eta \, . \, Q_{disp} \qquad (2.26)$$

The mechanical power Pmec is found through the thermal yield η. The percentage when evaluating the Canot cycle will be obtained by the amount of available heat (Qdisp). By being this, the efficiency of the electric generator is considered as stipulated in the manufacturer's manual.

3. RESULTS AND DISCUSSION

A brief comparison with the photovoltaic cogeneration mechanism, for example quoted as a double energy input in the TIER IV certification, it is possible to have on a photovoltaic plate, measuring 1.20m x 0.80m, about 30 photocells, each of which generates around 5 to 7 volts. For a total of 30 photocells present in said plate, we have something around 210 volts per plate.

The mechanisms discussed in this study, at its lowest performance, id est, the tower server has been dispensed with the 12 volts supplied by the motherboard and, moreover, would generate the 12 volts as a minimum cogeneration, through micro generator.

For sure only 12 volts does not mean much, but when it is thought on a Datacenter environment with thousands of processing units, of course the stereotype of cogeneration changes one's viewing angle.

3.1 Thermal Convection Results

Initially Table 1 gives theoretical and verified values for the tower server.

Table 1. Data generated from thermal convection simulation for spiral heatsink on tower server.

Input data - Literature	
Processor input heat	126
Temp. of fluid inlet [ºC]	26
Hydraulic Diameter [mm]	2
Heatsink thermal resistance	0,33
NUT to Swap Area	6,21
Volumetric Flow Rate [L / min]	1,875
Mass flow [kg / s]	1998,19
Reynolds	1666,54
Nusselt	14,11
Temp. Average Output Log [ºC]	72,02
Heat Transfer Rate [W]	3430,57

The verifying demonstrated the direct relationship between the pressure exerted by the flow velocity of the fluid and the heat transfer when it comes into contact with the surface of the processor, that is, as the Reynolds value increases, it also increases the value of Nusselt. It should be noted that the flow regimes for the fluid continue to show the Reynolds number> 3000 because, in order to better represent the data in the graph, the volumetric flow measurement scale was converted from ml / min to L / min.

Table 2 provides theoretical and verified values for the other cases, which are the secondary cooling cycles of the mainframe server and rack server and the primary cooling cycle of the Data Center.

Table 2. Data generated from thermal convection verification for heatsink with upper and lower transverse edges in other configurations.

Input - Literature			
Data	**Rack**	**Mainframe**	**Datacenter**
Temp. of fluid inlet [ºC]	3	- 40	8
Temp. of the fluid outlet [ºC]	83	60	70
Hydraulic Diameter [mm]	12	25,4	150
Thermal resistance of copper	0,33	0,33	0,33
Volumetric Flow Rate [L / min]	0,11	0,057	0,010
Mass flow [kg / s]	118,41	61,11	11,36
Reynolds	592,54	647,37	711,5

Figure 6 shows the Reynolds, Mass Flow and Velocity in (L / min), it is observed that the larger the diameter of the fluidic duct, the values for Reynolds tend to be smaller.

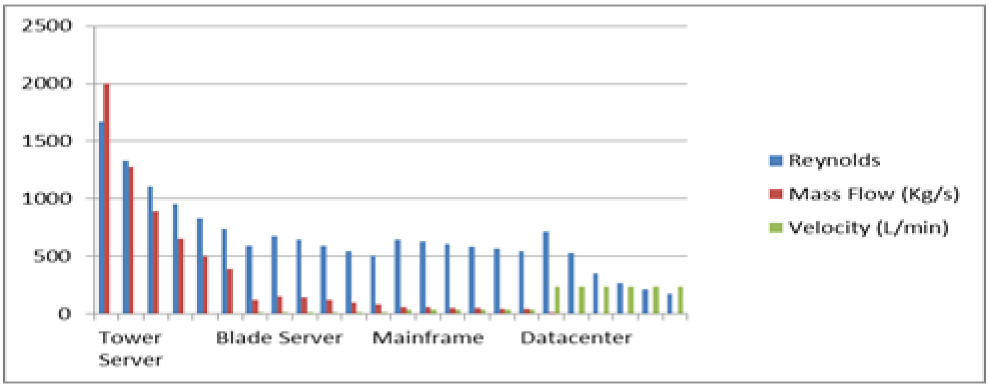

Figure 6 - Reynolds graph with mass flow and velocity (L / min).

The values for Nusselt and the medium logarithmic temperature were calculated only for the tower servers, this is due to the thermal exchange being directly on the processor base, through the square duct spiral sink, according to Figure 7.

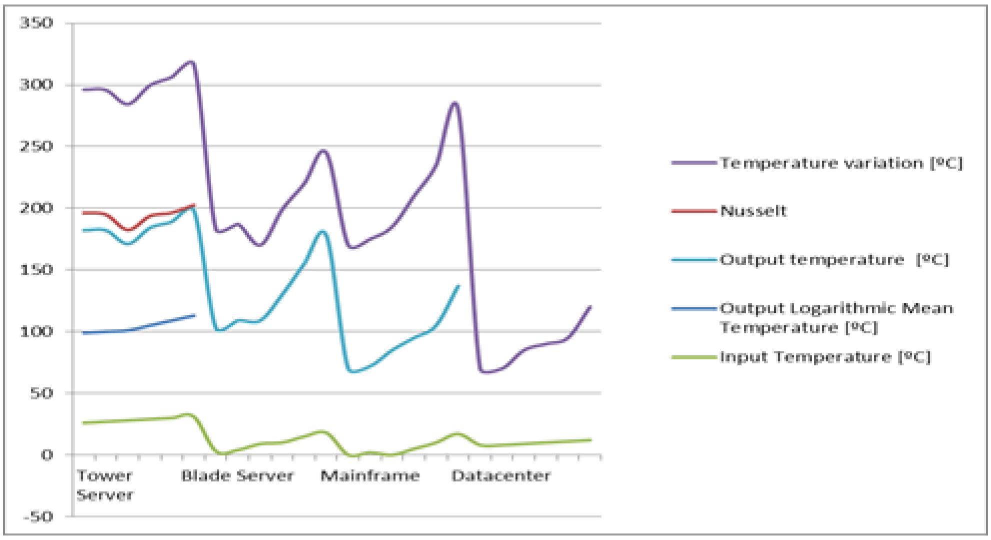

Figure 7 - Thermal transfer chart for the four configurations.

3.2 Stirling Engine Power Results

Table 3 shows the data that was collected through queries from manufacturers' manuals of processors, power supplies and data center equipment. It is worth mentioning the efficiency of the engine, which was used in the checks, the value of worse efficiency that corresponds to the number of Beale (0,11).

Table 3. Literature data for power calculation.

Data	**Tower Serv.**	**Rack Serv.**	**Mainfr.**	**Datace.**
Power [W]	45	150	5500	2028,33
Speed [rpm]	500	300	800	140
Average Pressure [KPa]	101,3	101,3	101,3	101,3
N. de Beale [rpm]	0,11	0,11	0,11	0,11
Temp. Compr. [ºC]	26	3	0	8
Temp. Expans. [ºC]	121	83	100	70
Const. Gas	286,9	286,9	286,9	286,9

Considering that the proposed model does not work with the counterpart of degeneration performed by air at room temperature, but with refrigerated fluid, the result of a faster movement of the piston of the Stirling engine was expected by studying the temperature variation in the respective mechanisms.

Figure 8 shows the power values provided by the tower and rack server mechanisms, as well as the resulting power generated by the motor in its respective environment.

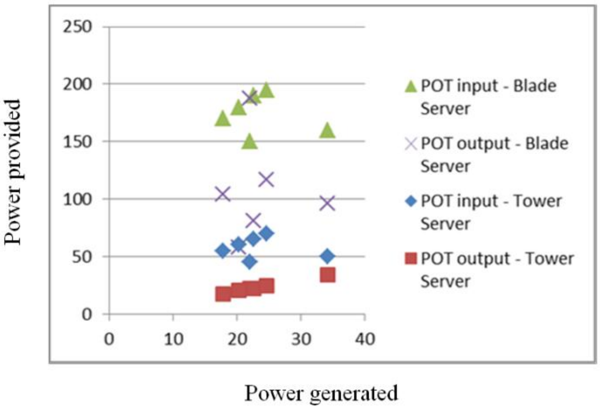

Figure 8 - Graph of the power supplied and generated for tower and rack servers.

Figure 9 shows the power values provided by the mainframe and data center configurations to the Stirling engine, as well as the resulting power generated by the motors in their respective mechanisms.

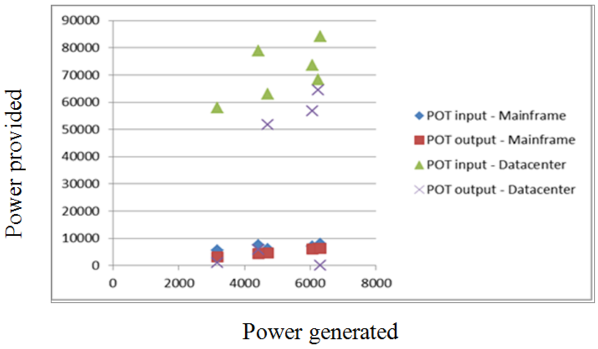

Figure 9 - Graph of the power supplied and generated for mainframe and datacenter servers.

In this case, the efficiency of the Stirling LTD engine has a thermal efficiency of 0.1% [23], after which the input power values were higher than the power output values in the motor performance, above all, it is observed that still power remains.

4. CONCLUSIONS

After the detailed study, based entirely on scientific and bibliographical research, it is possible to understand that the object of the present study is viable, intelligent and, mainly, sustainable solution to the cooling of said data processing centers, therefore capable of extract the temperature of the processor and electronic components in order to provide thermal energy to the new compound mechanism of heat sink for liquid and also Stirling LTD engine.

A relevant fact of the research was to combine two models in a synchronous way, which were the heat transfer modeling and power generation modeling of the Stirling LTD engine. This has made testing more costly since the interdependence of variables is inseparable. But the learning gained from manipulating these data and studying the behavior of results undoubtedly outweighed any effort.

Thus, it is concluded that, even assuming minimum values for the calculations in the theoretical experiment, all proposed mechanisms provide sufficient torque for the operation of electric generators at their different scales.

5. REFERENCES

[1] FERLIN, E. P. The technological advancement of processors and their use by software. Revista da Vinci, v. 1, n. 1, p. 43–60, 2004.

[2] MARIN, P.S. Data Centers. Unraveling each step: concepts, design, infrastructure and energy efficiency. Ed. Érica, 2011.

[3] <https://pt.uptimeinstitute.com/tiers>. Acesso em: Abril de 2018.

[4] <https://www.nexdatacenter.com/blog/data-center/types-and-tiers-of-data-centers/>. Acesso em: Abril de 2018.

[5] <http://www.datacenterdynamics.com/content-tracks/colo-cloud/google-to-expand-data-center-in-pryor-oklahoma/96998.fullarticle>. Acesso em: Abril de 2018.

[6] HAYWOOD, A.M. *et al*. Investigating a relationship among CPU and system temperatures, thermal power, and CPU tasking levels. In: 13th IEEE intersociety conference on thermal and thermomechanical phenomena in electronic systems (ITherm), San Diego, 2012.

[7] EBBERS, M. *et al*. The green data center: steps for the journey. 1. ed. IBM International Technical Support Organization, 2008.

[8] GROLL, E. *et al*. Mathematical modeling of scroll compressors—part I: compression modeling. International Journal of Refrigeration, v.25, pp. 731-750, 2002.

[9] IBM Corporation. Guia Técnico do mainframe IBM *zEnterprise* EC12 (REDBOOK), Secund Edition SG24-8049-01, EUA, December, 2013. Disponível em: <https://www.ibm.com/redbooks>Acesso em: Novembro de 2017.

[10] DAI, J., DAS, D., PECHT, M. Prognostics-based health management for free air cooling of data centers. Applied Energy, v. 99, pp. 423-429, 2012.

[11] ALMOLI, A. *et al*. Computational fluid dynamic investigation of liquid rack cooling in data centers. Applied Energy, v. 89, pp. 150 – 155, 2012.

[12] PATEL, C. *et al*. Computational fluid dynamics modeling of high compute density data centers to assure system inlet air specification. In: Proceedings of the Pacific Rim/ASME international electronics packaging technical conference and exhibition (InterPACK), Kauai, Hawaii, 2001.

[13] BOUCHER, T. *et al*. Viability of dynamic cooling control in a data center environment. Controls and Information Technology, EP-04-1163, BASH, 2006.

[14] BEJAN, A., ERRERA, M. Deterministic tree networks for fluid flow: geometry for minimal flow resistance between a volume and one point. Fractals, v. 05, n. 04, p. 685-695, 1997.

[15] BUCCI, A. *et al*. Water single-phase fluid flow and heat transfer in capillary tubes. In: 1st International Conference on Microchannels and Minichannels, pp. 319-326, January 1st, 2003.

[16] BIZARRIAS, W. Effects of cooling system pressure and ethylene glycol concentration on the cavitation characteristics of an automotive water pump. 2008. 136

f. Dissertation (Master in Mechanical Engineering) - Polytechnic School. University of São Paulo, São Paulo, 2008.

[17] OLIVEIRA, Rony. Heat Transfer Analysis of Thermal Fluids added with Ethylene Glycol and Polymers. Natal, RN. Dissertation (master's degree) - Federal University of Rio Grande do Norte, Technology Center, 2016.

[18] <https://www.onshape.com/>. Acesso em: Abril de 2018.

[19] INCROPERA, F.P.; DEWITT, D.P. Fundamentals of Heat and Mass Transfer, 6th edition, LTC - Technical and Scientific Books Publisher S. A., R. J. 2015.

[20] IBM Corporation. Power system site preparation and physical planning. Edition applies to IBM Power Systems, 2009.

[21] PHILLIPS, R. Forced convection, liquid cooled, microchannel heat sinks. MS Thesis, [s.l.] Massachusetts Institute of Technology, 1987.

[22] SCHMIDT, G. Theorie der Lehmannschen calorischen maschine. Zeit Des Vereines deutsch Ing, v. 15 (1-12), pp. 97–112, 1871.

[23] ARAGÓN-GONZÁLEZ, G. et al. Developing and testing low cost LTD Stirling engines. Revista Mexicana de Física, v. 59 (1), pp. 199 – 203, 2013.