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Internal variation temperature analysis and thermal mapping of a central processing unit (CPU)

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***Abstract*—*This work aims to analyze the internal temperature variation of the central processing unit (CPU) of a personal computer, through the development of three distinct scenarios: one for reference and two aiming at its performance improvement. The finite volume method (FVM) was applied. Thus, Hypermesh 13.0 software was used for geometric model development and for surface mesh generation. For model contour conditions configuration, virtual simulation and post-processing, Starccm+ software was used. The results of this work indicated hot spots due to the heat dissipated during the operation of the CPU components. As expected, the processor region presented the highest temperatures in all proposed scenarios. The opening on the side of the cabinet, proposed in scenario 2, allowed a temperature reduction of about 18 °C in the processor region. In turn, scenario 3, in which heat exchangers were used in order to minimize the temperature of the hot air from the recirculation in the processor region, showed a minimum temperature reduction (about 3 °C) when compared to scenario 1.*

Keywords*—*Air Drain, Cabinet, CPU, Fan, Heat Transfer.

I. INTRODUCTION

Currently, there is a wider growing technology development in the computer Science area, seeking to meet the demands of consumers, either by a better graphic interface or by a greater processing of data, among other factors [1]. The manufacturer of the hardware upon which this study is performed advises that computer internal temperature should not exceed 70 °C, since higher temperatures may penalize the system with reduction of life cycle and instability. Increasing data processing capacity generates a greater amount of energy dissipated inside the cabinet. So, it needs to be well scaled in order to extend his lifetime and to guarantee its better operation, avoiding additional maintenance costs. Nawawi [2] evaluated the internal temperature distribution in the central processing unit (CPU) of a computer and observed that the power supply, followed by the processor and the hard disk, were the components with the highest operating temperatures. The failure rate of electronic components increases as an exponential function with the increasing temperature operation. As a result, computer industry has been looking for better forms of ventilation inside the cabinet and also for more efficient equipment, besides studying their best positioning within the cabinet [3].

In order to identify feasible and effective proposals for cooling electronic components, several refrigeration techniques appeared, as water-cooler and heat pipe, that relies on heat transfer by moving heat from the base (hot) to the sink (cool) using a small amount of liquid. The emergence of these alternatives reflects the industries demand for better cooling technologies, rather than the use of air. However, these cooling techniques, when compared to air cooling, are costly, so it is important to apply advanced research into improving the performance of air-cooling technology.

Mohan and Govindarajan [3] used Computational Fluid Dynamics (CFD) method to study the air cooling of a 80 W processing unit (CPU). For this, the authors analyzed two different designs of the heat sink: fins with plate shape and fins with cylindrical shape. In addition, the fins thickness and type of material were varied, aiming to identify the best performance. In this model, it was considered the cooling of the heatsink made by a cooler. The results were compared with experimental data, which showed that the base plate constituted by the materials copper and aluminum presents higher performance, reaching lower temperatures, and that the increase of the fin thickness contributes to the reduction of the operating temperature.

Hariharan et al. [4] also studied alternatives to solving hot spot problems in laptop processing units, indicating the application of a loop heat pipe circuit to improve the cooling system. According to the authors, the advantage of this technology is the reduction of noise and the lower energy consumption, when compared to the heatsink.

The different technologies for processing unit cooling have different performances and may vary according to the geometric form, as studied by Elnaggar, Abdullah and Mujeebu [5]. This work consisted in the investigation of the efficiency of the insertion of heat pipe in L format for cooling a notebook CPU. The simulation was performed through finite element modeling, considering natural and forced convection modes. The authors observed that the cooling air flow rate and the incoming energy influence the overall flat fin heat pipe heat resistance. In forced convection, the overall thermal resistance was 3.67 °C/W, while for natural convection it was only 0.53 °C/W. Elnaggar, Abdullah and Mujeebu [6] also evaluated the performance of a CPU cooling but by vertical U-shaped heat pipe. The simulations were performed in ANSYS 10 software and their results indicated that the thermal resistance decreased with increasing heat input and coolant velocity. In addition, the authors observed the best performance when the heat tube was in vertical position in relation to the horizontal.

Considering the importance of identify the measures that can contribute to reducing the generation of hot spots and/or reduction of the operating temperature of the central processing unit components, this paper aims to perform the thermal mapping of the CPU. From the analysis of the results, three scenarios were developed: (1) reference simulation; (2) insertion of a set of openings in the opposite side cover to the processor; (3) insertion of additional heat exchangers in the processor area and the motherboard chipset. The construction of these scenarios allows identifying the best alternative to reduce the internal temperature of CPU operation.

II. METHODOLOGY

The CPU model developed was based on literature data [3], which show the dimensions and positioning of each component/equipment. Furthermore, the technical specifications were obtained from hardware vendors. The software called HyperMesh 13.0 was used for model development and for the first mesh generation, based with triangular elements. The generated model can be seen in Fig. 1.

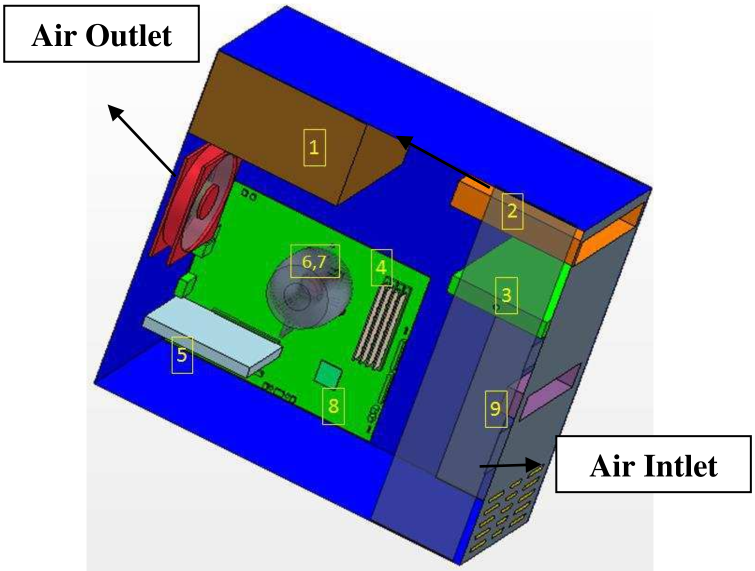

Fig. 1: Model of the CPU (1 – Electric Source; 2 – DVD ROM; 3 – HD; 4 – Memory; 5 – Graphics card; 6 – Processor; 7 – Core Processor; 8 – Motherboard chipset; 9 – Module on/off).

EVEREST Home Edition software was used to determine the temperature contour conditions used in the model. The manufacturers already adopt sensors that perform this monitoring in order to protect the equipment, however, these data are not accessible to the average user, justifying the use of the software, which accesses the temperature in real time measured in the desired component. During the measurement of the average temperatures of the components, the computer was excited through a high-definition video until reaching a plateau where the temperature variation did not exceed 2 °C. Only peak values were considered, since the study intends to make the thermal management in extreme conditions of operation, which justifies the environment temperature used (30 ° C).

TABLE 1 shows the dimensions and temperature contour conditions of each component used in the simulation and Fig. 2 indicates components dimensions and positioning. It was considered surface temperature for all but the processor. This was modeled with 80W thermal rejection, supplied by the manufacturer.

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Table.1:Component dimensions and temperature boundary conditions

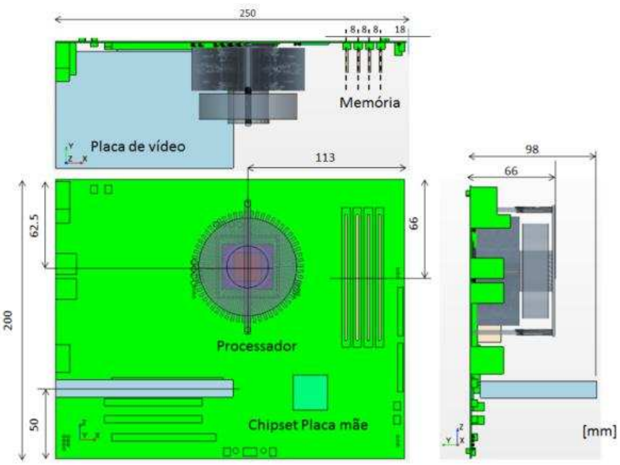
Component	Dimensions (mm) (L x A x P)	Surface temperature (°C)
Energy source	180,0 x 100,0 x 180,0	55
DVD ROM	170,0 x 30,0 x 150,0	35
HD	173,0 x 20,0 x 115,0	50
Memory	90,0 x 18,0 x 1,5	65
Video card	90,0 x 12,5 x 127,0	65
Processor	32,5 x 32,5 x 1,5	-
Core processor	20,0 x 20,0 x 1,5	-
Motherboard	25,0 x 25,0 x 1,5	60
Chipset		Adiabatic
On/off module	145,0 x 30,0 x 25,0	

TABLE 2 presents the characteristics of the materials that were configured in the model as solids. It is noteworthy that the other components were defined as bark and the heat exchanger was configured as adiabatic, as well as the on/off module.

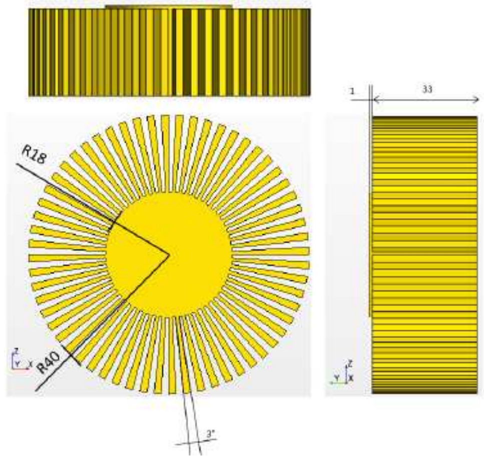
Table 2: Processor and heat exchanger characteristics

Characteristic	Processor	Heat exchanger
Material	Silicon	Aluminum
Density (kg/m³)	2.330	2.702
Specific heat (J/kg-K)	700	903
Thermal conductivity (W/m-K)	148	237

Source: Starccm+ Library, 2015.



(a)



(b)

Fig. 2: (a) Motherboard, processor, motherboard chipset, video card and memories; (b) Heat exchanger

In order to simulate the internal flow and the thermal exchange inside the CPU, the CFD simulation software Starccm+ was used, where the contour conditions for the model and the development of the volumetric mesh are imposed. It was based on the finite element mesh elaborated in the Hypermesh 13.0. TABLE 3 presents the input and output boundary conditions for the model developed. The air inlet speed of 2 km/h was adopted and the mass flow was defined.

Table 3: Model contour conditions.

Inlet		
Temperature	30,0	°C
Mass flow	0,0017	kg/s
Air density	1,1644	kg/m³
Outlet		
Temperature	30,0	°C
Manometric pressure	0	Pa

The fans were modeled as wafer and the boundary condition imposed was the pressure generated between the inlet and outlet surfaces, both of which were configured as adiabatic. The pressure values divided by the respective blade height provided the momentum defined in TABLE 4. These values were considered constant in the simulation.

Table 4: Fan input and output boundary conditions

Fan momentum		
Processor	2.206	N/m³
Computer	1.634	N/m³

Contour conditions were attributed in the Starccm+ software from the CPU shell model imported from

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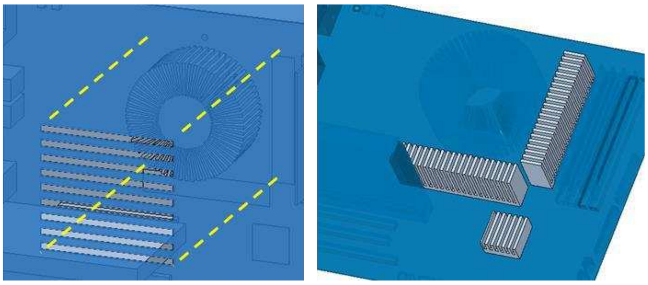
Hypermesh. The components configured as shell defined the internal volume of the processing unit. The processor and the heat exchanger, in addition to defining the internal volume boundaries, were also filled with mesh to define the energy transfer interface, as well as the fan wafers. The generated volumetric mesh was trimmer type, with approximately 800 thousand elements. The model simulated around 1500 iterations and converged, presenting residues below 0.001 and stabilized velocity and temperature values. In the post-processing, from the flow and temperature results, two new distinct scenarios were proposed, to improve CPU performance and component durability.

In scenario 2, rectangular gaps with dimensions 90mmx5mm were inserted in the opposite direction of the processor, as shown in Fig. 3a.



(a) **(b)**

Fig. 3. (a) Position of the gaps (b) position of the heat exchangers

In scenario 3, it was proposed to insert new heat exchangers in the side of the processor and in the motherboard chipset, according to Fig. 3b. Some manufacturers usually use this alternative as a thermal solution. The heat exchangers assembledat the side of the processor have dimensions of 86mmx30mmx15mm with fins 2 millimeters thick and 26 millimeters deep. For the motherboard chipset were established dimensions of 26mmx26mmx12mm with fins of 2mmx7mm.

III. RESULTS AND DISCUSSION

The simulations were performed aiming the evaluation of CPU air flow and internal temperature variation. The reference simulation (scenario 1) was performed considering the actual operating conditions of the CPU, at ambient temperature of 30 °C and the location of the components as specified in the methodology. Fig. 4 shows the results of the reference simulation for the motherboard, whose temperature reached indices from 54 °C. The region that presented the highest temperatures was the processor area, as it dissipated a larger amount of heat under operating conditions, as indicated by [2]. The high temperature in the motherboard components can cause problems in the welds and, consequently, cause this component to burn or an unstable operation. This proves the importance of applying an efficient cooling system, in order to reduce the operating temperature and thus contribute to the better performance of the system.

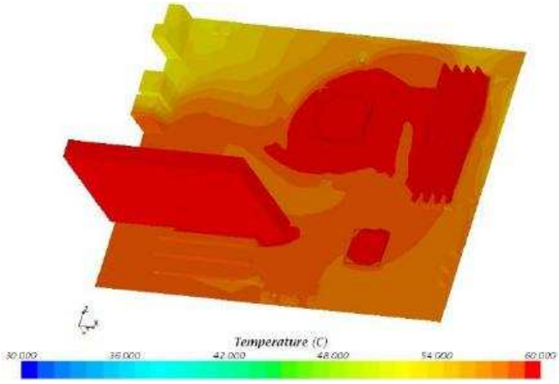


Fig. 4: Temperature variation on the motherboard in scenario 1.

Figure 5a shows the variation of the internal temperature, in a lateral cut of the CPU in the Y direction with depth equal to 84 millimeters. Despite the front air intake and the cooler in the rear region of the enclosure, there is a vortex of hot air in the processor region, which prevents the normal circulation of cold air and creates an air wall at the CPU cooler outlet, preventing the exit of the hot air.

Fig. 5b shows the temperature variation for the Z-direction cut with height equal to 140 mm, where can be noted a concentrated flow of hot air exiting the processor. The hot air hits the sidewalls and recirculates towards the processor, which reaches a temperature above 60 ° C.

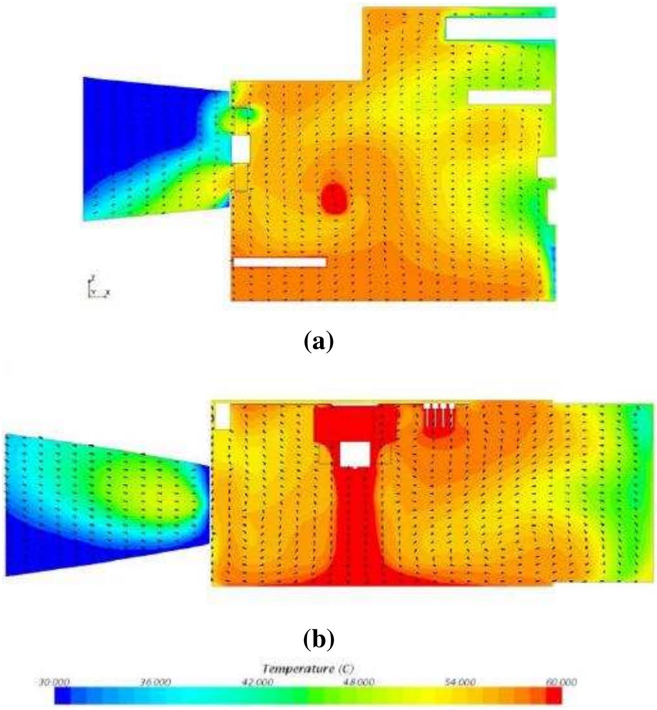


Fig. 5: Temperature and air flow variation in the CPU in scenario 1

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In order to improve air circulation and reduce internal CPU temperature, it was proposed to insert a gap in cabinet side in the region opposite to the processor (scenario 2). Fig. 6 shows the temperature variation in the motherboard for this scenario, in which temperatures around 37ºC were found. In comparison with scenario 1, there was a significant reduction in the temperature of the motherboard. The region of the processor which previously had temperatures above 60 ° C in its surroundings, with the gap in the cabinet started to present temperatures between 45 and 50 ° C approximately.

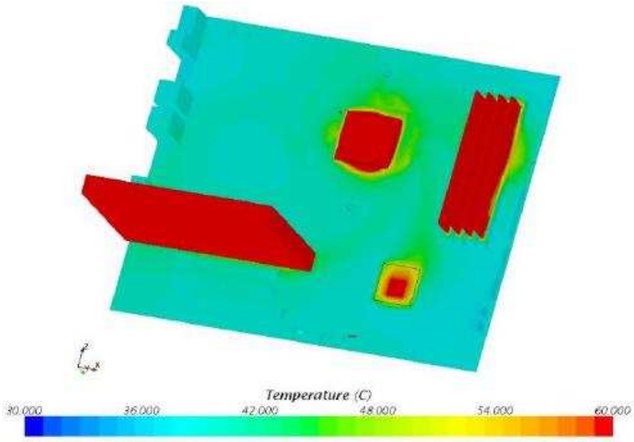
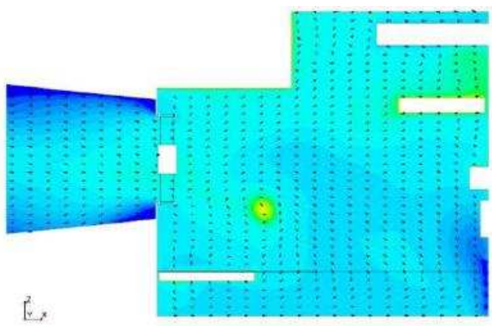


Fig. 6: Temperature variation on motherboard in scenario 2

As in scenario 1, the CPU internal temperature variation was observed for scenario 2, through the side cut in the Y direction with depth equal to 84 millimeters (Fig. 7a) and the cut in the Z direction with height equal to 140 millimeters (Fig. 7b). The opening in the region opposite to the processor allowed the discharge of the hot air that was previously trapped inside the CPU, allowing a temperature drop. In the case of the hot air flow generated by the heat dissipation from the processor, the opening contributed to guide it to the external environment, favoring the cooling inside the case. The hot air flow temperature of the processor fan reached values between 46 and 50 °C.



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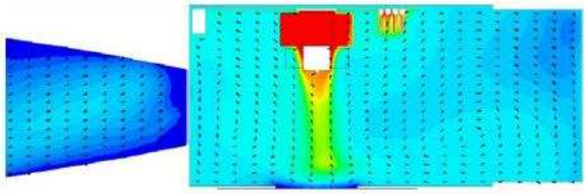

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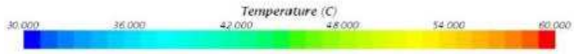

Fig. 7: Temperature and air flow variation in the CPU in scenario 2

In scenario 3 it was proposed the insertion of heat exchangers in the region surrounding the processor, in order to identify the best alternative for reducing the operating temperature of the CPU. It can be seen from Fig. 8 that the temperature in the region of the components has reduced about 3 °C compared to the reference scenario, even in the region that reaches indices above 60 °C. Despite the reduction of temperature, this alternative was not as satisfactory as scenario 2 (lateral gap). The motherboard remained at temperatures above 54 °C, which could affect the performance and durability of the components.

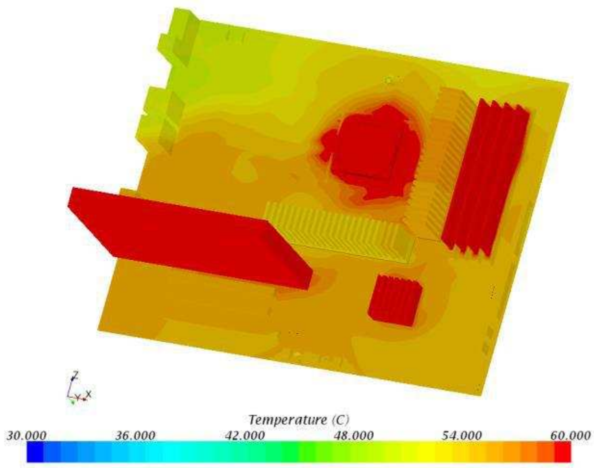

Fig. 8: Temperature variation on the motherboard in scenario 3

Fig. 9a shows that the hot spot relative to the heat flux generated by the heat dissipation of the processor continues at a temperature above 60 °C. In the case of scenario 2, the temperature of that hot area was reduced to approximately 50 °C, showing that insertion of the side opening is more advantageous technically. In Fig. 9b, although the heat jet reached a lower region and consequently lower recirculation, the temperatures of the motherboard remained practically the same as those of the reference scenario. These results indicate that the inclusion of heat exchangers around the processor and the motherboard chipset contributes to the reduction of the operating temperature of the CPU, but it remains high.

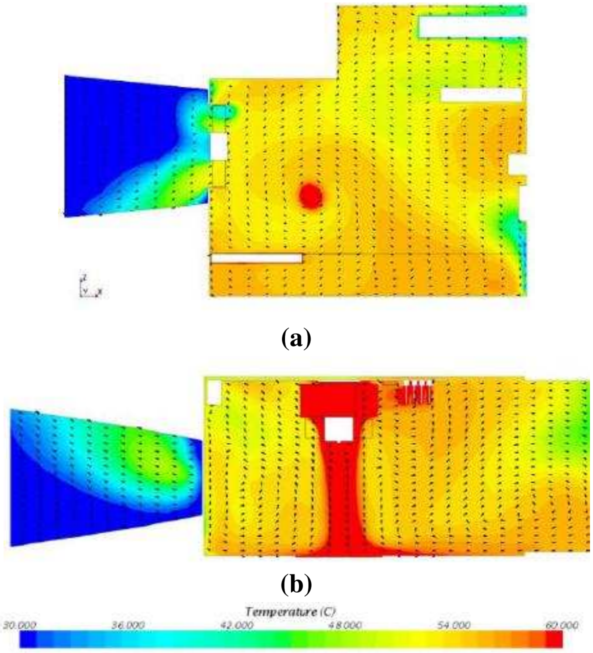

Fig. 9: Temperature and air flow variation in the CPU in scenario 3

IV. CONCLUSION

Increasing the data processing capacity of a CPU results in the generation of a greater amount of energy dissipated, causing an increase in the operating temperature. Considering the influence of temperature on the CPU operation, this work had as objective to evaluate the operating temperature of a processing unit and to propose measures to decrease it, thus increasing the durability of the components. Considering the defined objective, the results obtained in the simulation performed allows to conclude that the insertion of a gap in cabinet side in the region opposite of the processor significantly reduces the operating temperature inside the CPU (approximately 18 °C). The proposed gap allowed the hot air flow dissipated by the processor to be released to the external environment, avoiding much of the recirculation observed in the reference scenario.

The inclusion of heat exchangers in the processor region reduces the operating temperature of the CPU in about 3 °C. Despite being a viable alternative for allowance of temperature reduction, it is not as efficient as the insertion of the gap. This is because the presence of the heat exchangers does not solve the problems of recirculation at the same time that it does not facilitate the exit of hot air. In addition, the insertion of the side gap is simpler and less costly, since extra heat exchangers needs to be of specific materials and being designed according to thermal need. In this way, it is possible to conclude that the most technically feasible solution is the insertion of a gap in the side of the CPU, reducing the operating temperature and, consequently, increasing the lifespan of the components.

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