Design of An Experimental Device for the Analysis of the Influence of Sound Waves on the CPU Cooling Process - Part I

Lukáš Tóth[1*], Romana Dobáková[2]

Department of Energy Engineering, Faculty of Mechanical Engineering, Technical University of Košice, Slovakia
*Corresponding Author

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Abstract— *The article discusses the design and preparation of the experimental equipment for the analysis of the cooling power of air cooling at various operating parameters. The basis of the article is an analysis of the needs and maximum thermal output of the CPU. Subsequently, it presents the design of the experiment with the calibration requirements. It describes processes for creating a basic package of data as an initial point for experimental analysis and solving the problem of increasing the air-cooling efficiency using acoustic waves.*

Keywords— CPU, TDP, Cooling Process.

I. INTRODUCTION

The increasing output of computer components such as CPU and graphics cards involve the need to increase the outputs of cooling devices, whose task is to remove the heat generated during the operation of the computational parts of the computer. The increase in the amount of the removed heat is associated with an increase in the size of the cooling units, whether it is water or air cooling. However, the expansion of cooling systems is limited by the size of the space defined by the outer casing of the computer. Current cooling units, primarily the water-cooling take up a significant space at the outer walls. Therefore, increasing the cooling efficiency of computational computer components is starting to come to the fore in connection with the effort to minimize space a modern computer should occupy and with miniaturization, lightening and at the same time increasing the output of portable computers. One of the biggest limitations of current laptops, which causes their lower output in comparison to desktop computers, is precisely their inability to cool the computational components as efficiently as in comparison to a desktop computer.

II. THERMAL OUTPUTS OF CURRENT CPUS

Nowadays, the main indicator of the amount of necessary heat removed from the CPU – computational component, is the TDP value – Thermal Design Power, which, however, does not determine the maximum possible heat output of the CPU, but only the maximum heat output of the CPU during normal processes. During the processes that intentionally overload the CPU, there can be an increase in heat output, which needs to be dissipated from the surface to prevent any thermal damage to the cooled electrical components.

A significant problem is the TDP definition itself, since each manufacturer of the CPUs for computers defines individually, how this value is determined, and in some cases, the manufacturer has various definitions of TDP for different series of CPUs. As an example, we can use the TDP definitions of the two biggest manufacturers of CPU:

The AMD definition

- *"TDP is the maximum current the CPU can draw at the factory voltage and frequency under the worst thermal conditions."*

- TDP Thermal Design Power. The thermal design power is the maximum power a processor can draw for a thermally significant period while running commercially useful software [1].
- TDP Thermal design power. A power consumption parameter that is used in conjunction with thermal specifications to design appropriate cooling solutions for the processor [2].

Intel definition

- From the CPU datasheet with the Northwood core: "The number in this column reflects a recommended point and does not indicate the maximum power that the CPU can emit under the worst conditions".
- For the Prescott cores it has a different definition: *"TDP should be used as a target for cooling design for a given CPU. TDP is not the maximum thermal output the CPU can emit".*
- From Intel support: "*TDP stands for Thermal Design Power, in watts, and refers to the power consumption under the maximum theoretical load. Power consumption is less than TDP under lower loads. The TDP is the maximum power that one should be designing the system for. This ensures operation to published specs under the maximum theoretical workload*" [3].

Because of the reason given by inhomogeneity and non-uniform definition of TDP it is only possible to determine that TDP can be used for an approximate determination of the thermal output of the given CPU. Comparing, for instance, CPUs from AMD and Intel companies (or even any other CPU series from the same company) using TDP is simply not possible, due to the different interpretation of TDP by both companies. TDP also does not say anything about CPU consumption at low load (office work, ...), which is, for example, much more important for laptops than consumption at full load [4].

For the comparison in labelling and TDP values, a table was compiled with the TDP values of common types of CPUs used in desktop computers.

TABLE 1
PARAMETERS OF CURRENT CPU

Name	Number of cores	Frequency	Production technology	Number of fibres	TDP (W)
AMD Ryzen Threadripper PRO 5995WX	64	2.7 GHz	7 nm	128	280
Intel Core i9-13900KS	24	3 GHz	10 nm	32	253
AMD Ryzen 9 7950X3D	16	4.2 GHz	5 nm	32	120
Intel Core i9-11900K	8	3.5 GHz	14 nm	16	125
Intel Core i7-13700F	16	2.1 GHz	7 nm	24	219
Intel Core i5-13600KF	14	3.5 GHz	10 nm	20	181
AMD Ryzen 9 5900X	12	3.7 GHz	7 nm	24	105
AMD Ryzen Threadripper PRO 5965WX	24	3.8 GHz	7 nm	64	280

As can be seen in Table 1, it is not possible to establish any precise connection between the number of cores, fibres, and the thermal output of the CPU. The only thing that can be said with certainty is that with the increasing number of cores and with the increasing computional power, the heat output that needs to be removed from the surface of the CPU also increases. However, this value is not directly proportional, as seen on the example of CPU from AMD company, namely AMD Ryzen

Threadripper PRO 5965WX and AMD Ryzen Threadripper PRO 5995WX, when both have the same TDP, but in the case of the 5965WX version, the number of cores and of the fibres is half of that of the 5995WX (tab. 1).

III. DESIGN OF THE EXPERIMENT

Since it´s not possible to reach a general conclusion connecting the basic parameters of the CPU with its thermal power, which is caused both by different TDP definitions and also different working conditions of the CPU, it is necessary to create certain generalization of the thermal output that will be considered the maximum possible during the experiments. Due to this, an air cooler, for which the manufacturer indicates the maximum value of the heat output that this cooler can remove to the surrounding environment under maximum operating conditions, was chosen for the CPU. Based on this data, the maximum heat output for the simulated CPU was also chosen, since even in the case of a real CPU, there would be no greater heat dissipation than the maximum value given by the cooler manufacturer.

FIGURE 1: Deepcool AG200 [5]

For the experiment and determination of operating parameters, a commercially available model of air cooling with 2 heat pipes - DeepCool AG200, whose basic information is described in Table 2, was chosen.

TABLE 2
BASIC PARAMETERS OF THE DEEPCOOL AG200 [5]

Width	94 (mm)
Height	133 (mm)
Depth	66 (mm)
Number of heat pipes	2
Fan diameter	92 (mm)
Air flow	36.75 CFM
	62.44 ($m^3 \cdot h^{-1}$)
Maximum loudness	30.5 (dB)
Maximum speed	3050 RPM
Minimum speed	500 RPM
Weight	304 (g)
Maximum TDP	100 (W)

As a CPU simulation with a uniform temperature field distribution, an aluminium block was used, with dimensions of 58, 85 a 16 mm, in which 3 heating modules, each with the maximum power of 50W and diameter of ø6 mm, were placed. The maximum heat output of the simulated CPU was 150W, which is 50W more than the manufacturer's maximum TDP for the cooler, which is 100W. 3 NTC 10K thermometers with a diameter of ø5 mm were also placed in the body, and 6 DS18B20 and SMT172R16A thermometers were installed on the surface of the device. The task of the given number of thermometers is to ensure the scanning of the distribution of the temperature field within the aluminium block and to determine the maximum temperature reached during the cooling process. The distribution of the heating modules is shown on the Figure 2.

Thermometers SMT172R16A were placed on the sidewalls of the aluminium block, temperature sensors DS18B20 were placed on the top and bottom of the aluminium block.

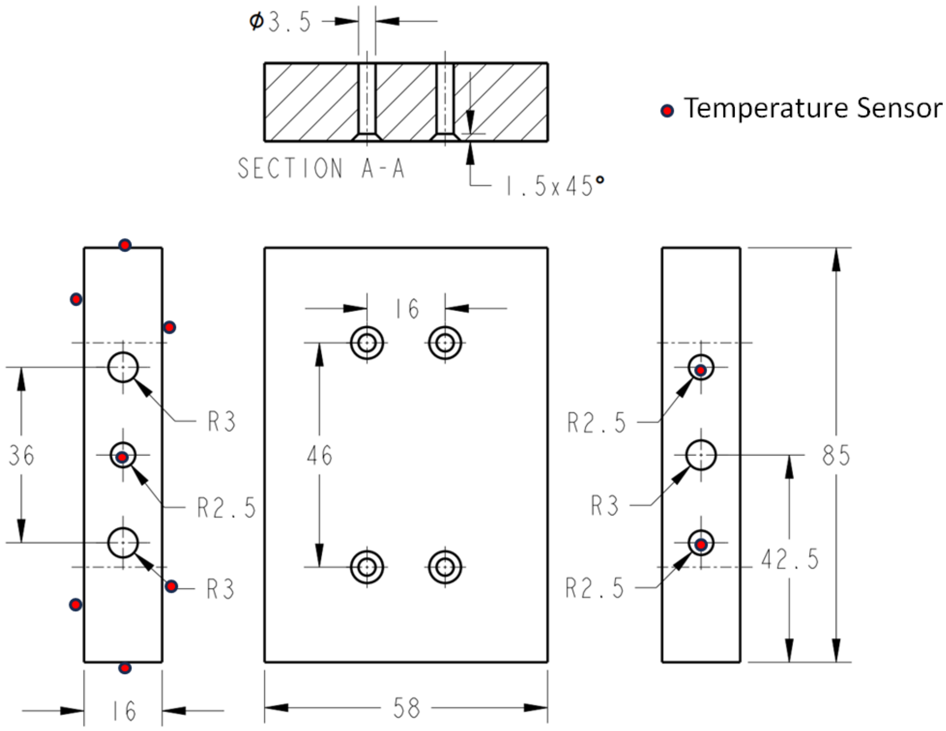

FIGURE 2: Parameters of the CPU simulator with the indication of the location of the temperature sensors

The entire aluminium block is isolated with rubber insulation with the width of 10 mm, on which there is a reflective aluminium layer.

Another set of thermometers together with an anemometer is in the area of the fan and cooler plates, where they record the distribution of the temperature field along the layers of the cooling plates, the air temperature before entering the fan and after exiting the area of the cooling plates. The air coming out of the cooling plates travels into a conical-shaped collector, at the end of which there is a propeller anemometer for determining the amount of air passing through the body of the cooler at different power settings of the fan.

The basis of the calibration experiments was the creation of a database determining the cooling power of the CPU air cooler under certain output conditions given by fan revolution speed and ambient temperature. With the help of heating modules, where the heat output was increased and decreased during each series of measurements, the temperature of the aluminium block simulating the CPU was stabilized. After the stabilization of the aluminium block, the amount of heat supplied by the heating modules equals the cooling output of the cooler under given output conditions. Thanks to the knowledge of the voltage and the current supplied to the heating modules, it is possible to determine relatively precisely the cooling power for the given output parameters of the cooler determined by the fan speed and the ambient temperature. The regulation of the fan revolution speed, along with the scanning of the current value of the fan rotation speed, was carried out through the Arduino MEGA microcontroller. The set speed range was set from the lowest possible, given by the manufacturer at a value of 500 rpm to a maximum of 3000 rpm. The fan speed was increased by 500 rpm for each series of measurements. At the same time, the Arduino serves as a bus for the values of the measured temperatures from the CPU simulator and the distribution of the temperature field within the cooler.

IV. SENSOR CALIBRATION

Since NTC sensors are used to measure temperatures, in which their resistance changes along with the change in temperature, i tis necessary to calibrate each sensor due to small inaccuracies, which may occur during the production process. These inaccuracies may subsequently cause measurement deviations in the range of tenths to several degrees. Such deviations are unacceptable but can be reduced with calibrating the sensors. To calibrate the sensors, a water bath with a precisely defined temperature, an integrated temperature sensor and an external Alhborn PT 100 thermometer connected to the ALMEMO 2890-

9 data bus were used. Multiple check ensures an increase in the accuracy of sensor calibration. The water bath was chosen due to its easy handling and the possibility to change temperature, which is the same throughout the entire volume of the liquid, within degrees in the range of measurement from 25 °C - room temperature in the laboratory, up to a temperature of 70 °C, which we consider to be the maximum for use CPU.

Each sensor was labelled and in Table 3 we can see the example of how the resistance of the thermistors changed with the change in the temperature. As can be seen in Picture 3, there is no linear change in the resistance of the thermistors, but there is a curve, and the curve is partially different for each thermistor. Such differences occur due to imprecise resistance values and production deviations in the production of thermistors.

TABLE 3
DIGITAL SIGNALS SENT BY SENSORS T1-T4 AT DIFFERENT TEMPERATURE

	Temperature (°C)							
	35	40	45	50	55	60	65	70
T1	413	364	321	291	268	252	240	204
T2	412	363	320	286	263	245	231	203
T3	412	363	317	280	247	220	197	174
T4	407	358	312	272	235	202	174	157

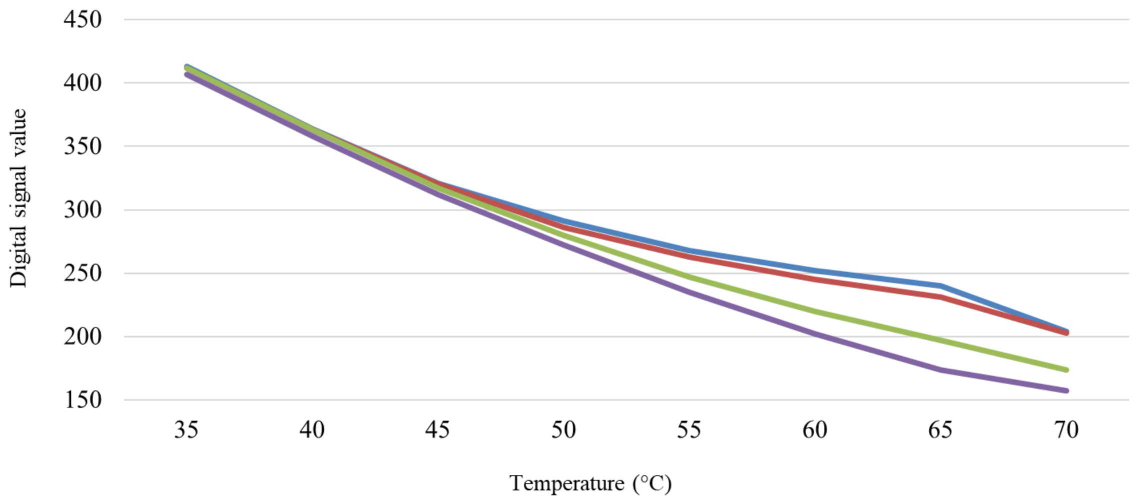

FIGURE 3: Graphic representation of the change in digital signal from the T1-T4 sensors during the temperature change

Measuring of changes in the value of the 10K thermistors was recorded using an Arduino MEGA microcontroller on analog inputs that can record a signal in the range of 0-1024. A prescribed resistance was placed across the thermistor as shown in Figure 4.

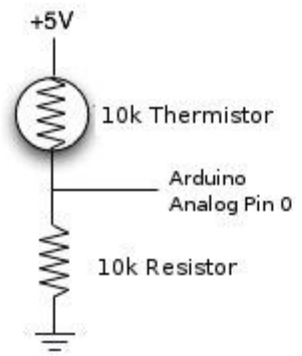

FIGURE 4: Thermistor connection diagram

The calibration of the digital sensors took place under the same conditions. The accuracy of selected temperature sensors caries in the case of DS18B20 in the range of ±0,5°C. Because of this, several sensors are placed in different places within the aluminium block and the temperature of the block is given as the average measured value of these sensors in a stable state, when there was no temperature change. We connected all DS18B20 sensors using a common 1-Wire bus to the Arduino Mega microcontroller. Thanks to the unique 64-bit identifier of each DS18B20 sensor, individual sensors can be directly addressed, which allows us to assign them to specific positions. The disadvantage of such connection is a slower loading of data since all temperature sensors share one common data bus. In the case of a stable state, it´s not necessary to carry out a series of measurements following in short time intervals; therefore, this method of connection was chosen as more economical. The advantage is also the reduction of the number of conductors passing through the aluminium block insulation, which also reduces the amount of heat dissipated to the surroundings.

V. CONCLUSION

The article described the design of a system for the analysis of increasing the efficiency of CPU cooling using an air cooler. Calibration of the temperature sensors distributed within the aluminium block simulating the CPU was carried out. The calibration was also performed on the thermistors located between the ribs of the air cooler and at the inlet and outlet of the cooling air.

The basic calibration and creation of an initial comparison data package of the cooling power of the air cooler at different operating parameters will be described in the second part of this article.

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