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Thermoelectric Power Generated from Computer Waste Heat

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Abstract
Computer components generate heat as the computer process information. This leads to a subsequent rise in their operating temperatures while the failure rate of computer components increases almost exponentially with the operating temperatures. The heat generation leads to wastage of energy yet there exist energy crisis in the world. This study has evaluated the thermoelectric voltage that can be generated from the waste heat of Dell desktop computer under varying processor workloads. Type J thermocouples were used to tap and convert the waste heat in the desktop computers to thermoelectric voltage. 2286/5 data logger was used to make the temperature and the corresponding generated thermoelectric voltage measurements of the thermocouples. Usable amounts of thermoelectric voltage can be generated from the waste heat of the desktop computers using thermocouples.
Keywords; Thermoelectric effect, Thermoelectric voltage, Computer waste heat

1 Introduction

Thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. The term "thermoelectric effect" encompasses three separately identified effects. The Seebeck effect, Peltier effect and Thomson effect which are thermodynamically reversible (Long, 2001). The Seebeck effect is the conversion of temperature differences directly into electricity. The voltage created by this effect is on the order of several microvolts per Kelvin difference (Chen, *et al.,* 2009). The voltage V developed can be derived from;

$$V = \int_{T1}^{T2} S_B(T) - S_A(T)\, dT \qquad \text{.......} 1$$

Where S_A and S_B are the thermo powers of metals A and B as a function of temperature and T_1 and T_2 are the temperatures of the two junctions.

The thermo power or Seebeck coefficient, denoted by S of a material is the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material and the entropy per charge carrier in the material (Ferreira and Kim, 2008). The absolute thermo powers for different types of metals are equal to the ratio of the specific heat of the carrier to its electronic charge. The see beck coefficients are non-linear as a function of temperature and depend on the conductor's absolute temperature, material and molecular structure (Mc Gee, 1988).

The Seebeck effect is caused by charge carrier diffusion and phonon drag. An applied temperature difference causes charge carriers in the material to diffuse from the hot side to the cold side, leaving behind their oppositely charged and nuclear at the hot side, giving rise to a thermoelectric voltage (Long, 2001). Phonons move against the thermal gradient and lose momentum by interacting with electrons (or other carriers) and imperfection in the crystal. If the phonon-electron interaction is predominant, the phonons will tend to push the electrons to one end of the material, hence losing momentum and contributing to the thermoelectric field. This contribution is most important in the temperature region where phonon-electron scattering is predominant (Ferreira and Kim, 2008). This happens for;

$$T = \frac{1}{5}\vartheta_D \qquad \text{where } \theta_D \text{ is the Debye temperature}$$

If the temperature difference between the two ends of a material is small, then the thermo power of a material is defined approximately as (Mc Gee, 1988):

$$S = \frac{\Delta V}{\Delta T} \qquad \text{.......} 2$$

and a thermoelectric voltage of ΔV is observed at the terminals.

A thermocouple is a junction between two different metals/alloys that produces a voltage related to a temperature difference on each side and creates a temperature difference when a voltage is applied to it. Thermocouple operation is based on the Seebeck effect or thermoelectric effect (Long, 2001). Every metal/alloy has a unique electronic and crystalline structure hence the allowed energy states and their electronic population will also be unique. When the two metals come in contact, the electrons in the metal with high energy will flow into the one with the lower energy. This occurs until the excess electrons in the metal of lower energy builds up a reverse EMF which opposes the flow; this occurs when all the electrons in both energies come to common Fermi energy E_f intermediate between the two (McGee, 1988). Thermocouples are a widely used type of temperature sensor for measurement and control and can also be used to convert heat into electric power.

The figure of merit Z for thermoelectric devices is defined as;

$$Z = \frac{S^2}{\rho K} \qquad \ldots\ldots 3$$

Where ρ is the electrical resistivity, K is the thermal conductivity and S is the see beck coefficient. The dimensionless figure of merit ZT is formed by multiplying Z with the average temperature (Ferreira and Kim, 2008).

The efficiency of thermoelectric device for electricity generation is given by η, defined as,

$$\eta = \frac{\text{energy provided to the load}}{\text{heat energy absorbed at the hot junction}} \qquad \ldots\ldots 4$$

The maximum efficiency η_{MAX} is defined as,

$$\eta_{MAX} = \frac{T_H - T_C}{T_H} \frac{\sqrt{1+Z\overline{T}} - 1}{\sqrt{1+Z\overline{T}} + \frac{T_C}{T_H}} \qquad \ldots\ldots 5$$

Where T_H is the temperature at the hot junction and T_C is the temperature at the surface being cooled. $Z\overline{T}$ is the modified dimensionless figure of merit (Ferreira and Kim, 2008).

2 Method

2.1 Materials

Dell desktop computer (P4: 2.8GHZ, RAM: 5.2MB, HDD: 40GB), Compaq CRT monitor, six type J thermocouples (iron-constantan) and 2286/2285 data logger were used for the study.

2.2 Thermoelectric voltage measurement

Type J thermocouples were connected to the heat generation modules (processor, north bridge, south bridge, HDD and monitor) of the desktop computer to tap the waste heat from the desktop computer and convert it to thermoelectric energy. The processor workload was varied as follows: one process - windows media player, two processes - windows media player and scanning(Avast antivirus), three processes - windows media player, VLC media player and scanning, four processes - double scanning, windows media player and VLC media player for all the desktop computers. 2286/5 data logger was used to measure the thermocouples temperature and the corresponding thermoelectric voltage generated. The thermocouples were terminated at the isothermal input connector (option -175) of the data logger. The thermoelectric voltage measurements were done for the computer under varying processor workloads, first with the heat sinks on then with the heat sinks off. The processor heat sink and fan were removed.

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3 Results

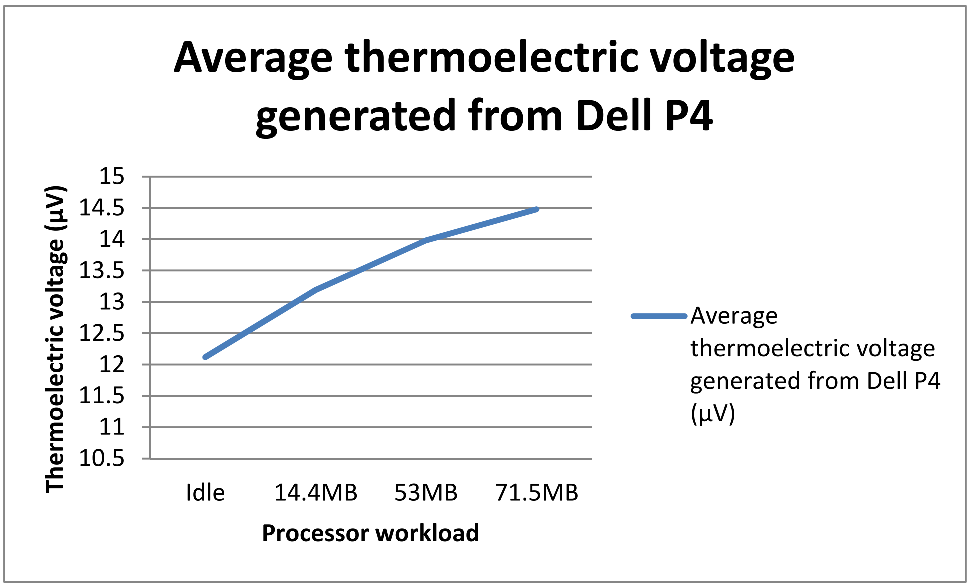

Fig 1: Thermoelectric voltage generated from waste heat in Dell P4 computer (with heat sinks ON) under varying processor workload.

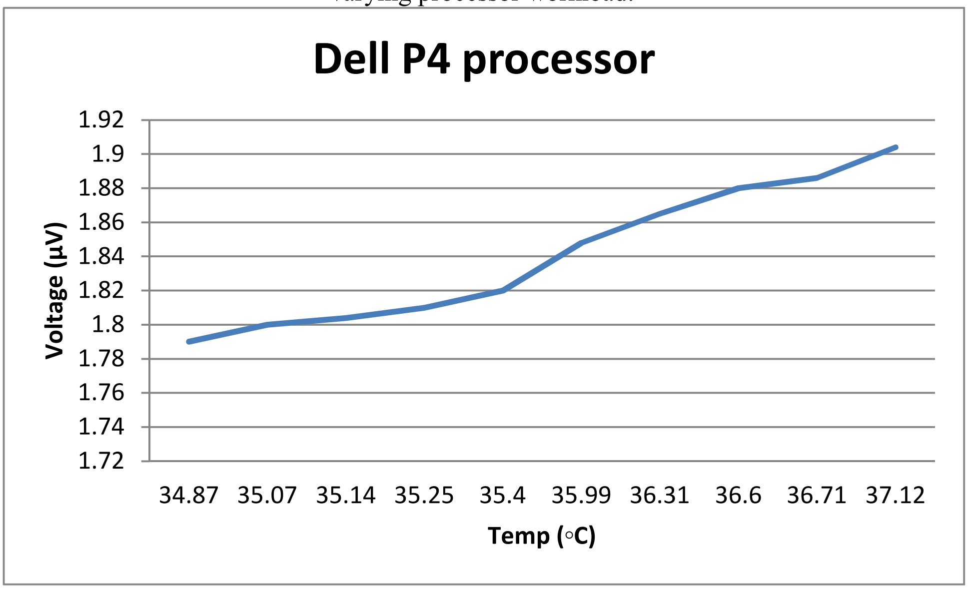

Fig 2: Increase in thermoelectric voltage with temperatures in the processor of Dell P4 computer.

4 Discussion

The measurements were taken with room temperature as the reference junction, but because most thermocouples are calibrated using ice point as the reference junction, reference junction (voltage) corrections must be made. Thermocouples terminated at the isothermal input connector of the 2286/5 data logger use permanently stored voltage/temperature compensation and voltage/temperature linearization algorithms so cold junction compensation had been performed for the thermoelectric voltage measurements taken.

Limited to the heat generation modules considered, a thermoelectric voltage of 8.134-9.889 µV was generated from the waste heat of Dell desktop computer. Figures 1 and 2 show that the thermoelectric voltage generated increases with increase in processor workload and temperatures respectively since thermocouples operation is based on Seebeck effect in which any conductor subjected to a thermal gradient generates a voltage. However with the heat sinks off as described above, a faster rise in temperature hence thermoelectric voltage generated was observed in the processor of the computer, the processor temperature reached a maximum at 83.13˚C as shown in table 3. The maximum thermoelectric power generated by the type J thermocouples from the waste heat of the desktop computer can be calculated as follows using equation 2;

Dell P4 desktop computer, $S = \dfrac{3.325}{63.95} = 0.05199\,\mu V/^{\circ}C$

Dell P4 processor with the heat sink and fan removed, $S = \dfrac{4.354}{83.13} = 0.0524\,\mu V/^{\circ}C$

The average maximum thermoelectric power produced by the thermocouple is therefore 0.052 μV/°C.
Type J thermocouples positive wire (iron) has electrical resistivity of 9.67μΩ-cm and a thermal conductivity of 0.162s-cm^2-°C while the negative wire (constantan) has electrical resistivity of 48.9μΩ-cm and a thermal conductivity of 0.0506s-cm^2-°C (Mc Gee, 1988).
The figure of merit for the thermocouple positive wire is calculated as follows using equation 3;

$$Z = \frac{0.052^2}{9.67 \times 0.162} = 0.00176$$

And that of the thermocouple negative wire is;

$$Z = \frac{0.052^2}{48.9 \times 0.0506} = 0.00109$$

The dimensionless figure of merit can be approximated to be;

$$Z\overline{T} = \frac{63.478 \times 0.001425}{2} = 0.045$$

The values obtained for the thermocouple dimensionless figure of merit indicates a low thermodynamic efficiency for the thermocouples. The maximum thermodynamic efficiency of the thermocouple can therefore be approximated as follows using equation 5;

$$\eta_{\max} = \frac{84.99 - 19}{84.99} \frac{\sqrt{1 + 0.045} - 1}{\sqrt{1 + 0.045} + \dfrac{19}{84.99}} = 0.0137 = 1.37\%$$

With 100% efficiency of the thermocouples the average thermoelectric voltage generated from the waste heat of the desktop computer under the varying processor workloads would be as shown in table 1

Table 1: The average thermoelectric voltage generated from Dell P4 desktop computer waste heat

Processor workload	Average thermoelectric voltage generated (μV)	Average max thermoelectric voltage that can be generated (V)
Idle	8.134	0.594
One process	8.978	0.655
Two processes	9.575	0.699
Three processes	9.889	0.722

Conclusions

- The thermoelectric voltage generated from the waste heat of the desktop computer increases with increase in temperatures and the number of processes the computer runs.
- Faster rise in temperatures hence thermoelectric voltage generated is observed when the heat sink of the computer is off.
- With the heat sink off, higher amounts of thermoelectric voltage are generated from the waste heat of the desktop computer.
- Type J thermocouples have a low thermodynamic efficiency of 1.37%**.**

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Table 2: Thermoelectric voltage generated from waste heat in a Dell P4 desktop computer (with heat sinks ON) under varying processor workload

Processor workload	Time (sec)	North bridge		South bridge		Processor		HDD		Total thermoelectric voltage (μV)
		Temp (◦C)	Volt (μV)	Temp (◦C)	Volt (μV)	Temp (◦C)	Volt (μV)	Temp (◦C)	Volt (μV)	
Idle	10	55.02	2.85	33.03	1.694	34.87	1.79	30.14	1.54	7.874
	20	56.27	2.91	33.43	1.715	35.07	1.8	30.48	1.56	7.985
	30	56.83	2.94	33.57	1.722	35.14	1.804	30.54	1.564	8.03
	40	57.25	2.97	34.04	1.747	35.25	1.81	30.67	1.57	8.097
	50	57.53	2.98	34.34	1.762	35.40	1.82	30.99	1.587	8.149
	60	57.77	2.99	34.54	1.773	35.99	1.848	31.12	1.594	8.205
	70	57.84	3	34.71	1.782	36.31	1.865	31.25	1.601	8.248
	80	58.00	3.009	34.87	1.79	36.60	1.88	31.75	1.627	8.306
	90	58.27	3.023	35.03	1.798	36.71	1.886	31.94	1.637	8.344
	100	58.41	3.029	35.40	1.82	37.12	1.904	32.03	1.641	8.394
One process	10	58.68	3.045	35.36	1.816	43.11	2.221	32.29	1.655	8.737
	20	59.11	3.067	35.61	1.828	43.21	2.227	32.40	1.661	8.783
	30	60.17	3.124	35.98	1.848	43.58	2.246	32.67	1.674	8.892
	40	60.62	3.148	36.23	1.86	43.75	2.255	32.80	1.68	8.943
	50	60.80	3.157	36.44	1.872	43.98	2.267	33.08	1.697	8.993
	60	60.93	3.164	36.72	1.886	44.07	2.272	33.41	1.714	9.036
	70	61.10	3.173	36.99	1.9	44.23	2.28	33.83	1.736	9.089
	80	61.25	3.181	37.18	1.91	44.52	2.297	34.03	1.746	9.134
	90	61.32	3.184	37.64	1.935	44.64	2.302	34.10	1.75	9.171
	100	61.51	3.195	37.95	1.951	44.75	2.308	34.37	1.764	9.218
Two processes	10	61.74	3.207	38.05	1.956	44.87	2.314	38.33	1.97	9.447
	20	61.82	3.211	38.25	1.967	44.90	2.315	38.53	1.981	9.474
	30	61.99	3.22	38.42	1.975	45.06	2.324	38.76	1.993	9.512
	40	62.10	3.226	38.60	1.985	45.12	2.327	38.92	2.002	9.54
	50	62.21	3.232	38.71	1.991	45.21	2.332	39.02	2.007	9.562
	60	62.34	3.239	38.88	1.999	45.33	2.338	39.21	2.017	9.593
	70	62.38	3.241	38.97	2.004	45.42	2.343	39.39	2.026	9.614
	80	62.49	3.247	39.12	2.012	45.56	2.351	39.56	2.035	9.645
	90	62.55	s3.251	39.27	2.02	45.68	2.357	39.69	2.042	9.67
	100	62.73	3.26	39.40	2.027	45.76	2.361	39.92	2.054	9.702
Three processes	10	62.88	3.268	39.51	2.032	45.92	2.369	40.09	2.063	9.732
	20	62.92	3.271	39.61	2.038	46.05	2.377	40.36	2.077	9.763
	30	63.08	3.279	39.77	2.046	46.22	2.385	40.65	2.092	9.802
	40	63.26	3.288	39.86	2.051	46.33	2.391	40.86	2.104	9.834
	50	63.35	3.293	39.96	2.056	46.57	2.4	41.04	2.113	9.862
	60	63.43	3.298	40.07	2.062	46.72	2.411	41.41	2.132	9.903
	70	63.55	3.304	40.18	2.067	46.84	2.418	41.51	2.138	9.927
	80	63.7	3.312	40.26	2.072	46.92	2.422	41.7	2.147	9.953
	90	63.88	3.322	40.34	2.076	47.32	2.443	41.85	2.155	9.996
	100	63.95	3.325	40.42	2.08	47.97	2.477	42.02	2.164	10.046

Table 3: Thermoelectric voltage generated from waste heat in a Dell desktop computer (with heat sinks OFF) under varying processor workload.

Processor workload	Time (sec)	Processor (with heat sink and fan removed)	
Idle		Temp (◦C)	Volt (µV)
	10	30.72	1.573
	20	42.69	2.2
	30	50.42	2.607
	40	54.57	2.827
	50	57.92	3.005
	60	61.11	3.174
	70	64.75	3.368
	80	69.77	3.636
	90	74.46	3.888
One process	10	32.4	1.661
	20	48.61	2.511
	30	59.09	3.067
	40	62.96	3.273
	50	73.02	3.81
	60	82.72	4.332
	70	83.13	4.354

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