HEAT TRANSFER CHARACTERIZATION OF AIR CIRCULATION INSIDE A SYSTEM OF STACKABLE ELECTRONIC DEVICES

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To Allah,

My beloved family, my wonderful wife and my beautiful daughter

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In the name of Allah, the most Gracious, the most Merciful

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ABSTRAK

Tujuan kajian ini dilaksanakan adalah untuk mengenal pasti keupayaan sistem pengudaraan di dalam sebuah sistem yang mengandungi peranti elektronik bertingkat dalam memindahkan haba yang dihasilkan daripada empat unit pemproses komputer (CPU) Intel J1900 berkapasiti 10W. Setiap CPU telah diasingkan di antara satu sama lain dengan unit diletakkan di dalam empat peranti elektronik yang berasingan yang disusun di antara satu sama lain dan diapit di antara ruang bekalan udara sejuk di bahagian bawah dan ruang ekzos di bahagian atas. Model matematik yang digunakan untuk tujuan kajian telah ditentusahkan melalui pengesahan terhadap masalah yang dijadikan penanda aras untuk sebarang masalah perolakan paksa dan perbandingan keputusan kajian menunjukan persetujuan yang baik. Kesan pemanasan akibat geseran dalaman di antara cecair dan permukaan, keapungan, kelajuan kipas penyejukan dan kedudukan susun peranti telah dianalisis menggunakan perisian ANSYS Fluent versi 16. Persamaan Navier-Stokes telah diselesaikan dalam simulasi pemindahan haba secara konjugat di mana pengaliran berlaku dari CPU ke dalam sirip penyejuk dan papan litar utama "mini-ITX" dan seterusnya melalui perolakan paksa oleh sistem pengudaraan ke persekitaran. Keputusan kajian menunjukkan, bagi mencegah kegagalan CPU semasa beroperasi, kelajuan minimum kipas penyejuk yang diperlukan ialah 1.0 m/s dan material kasing yang dipilih perlu mampu untuk mengekalkan sifat fizikal, sekurang-kurangnya pada suhu 76 °C.

ABSTRACT

The purpose of this study is to investigate the ability of forced circulated air inside a system of stackable electronic devices in transferring heat generated from four identical Intel J1900 10W computer processor unit (CPU). Each CPU was isolated from each other by locating it inside four separated electronic devices which are stacked on each other and sandwiched between cool air supply chamber at bottom and exhaust chamber at top. Validation of numerical model against a benchmark forced convection problem was performed and compared results are in good agreement. Effect of viscous heating, buoyancy, cooling fan speed and device stacking level were numerically analyzed by commercially available computational fluid dynamics (CFD) software ANSYS Fluent version 16. Navier-Stokes equations were solved in simulation of conjugate heat transfer where conduction occurs from CPUs into heatsink and mini-ITX motherboard and subsequently via forced convection of circulated air into environment. Results show that cooling fan speed of 1.0 m/s for prevention of CPU failure during operation is the minimum allowable speed and selected enclosure material should be able to withstand at least 76 °C of near wall temperature.

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LIST OF SYMBOLS

AR - Aspect ratio
c - Speed of sound
g - Gravitational acceleration
H - Height
k - Turbulent kinetic energy
k_{air} - Thermal conductivity of air
k_{eff} - Effective thermal conductivity
k_t - Turbulent conductivity
$\mathcal{L}$ - Characteristic length
L - Length
L_{pmin} - Minimum path length
L_{pmax} - Maximum path length
M_a - Mach number
Nu - Nusselt Number
p - Pressure
Q - Total surface heat flux
Re - Reynolds number
R - Ideal gas constant
S - Source term
SST - Shear Stress Transport
T - Temperature
$T_{junction}$ - Junction temperature
u - Velocity in x-direction
u_A - Cross section area velocity
$\bar{u}$ - Mean velocity
u' - Fluctuating velocity

v - Velocity in y-direction

$v_{Re_{10}}$ - Velocity based on Re

$\vec{V}$ - Velocity vector

V_a - Velocity of air

w - Velocity in z-direction

W - Width

X - Domain length

Y - Domain height

Z - Domain width

ε - Turbulent dissipation

μ - Dynamic Viscosity

ρ - Density

ϕ - Scalar quantity

ω - Specific rate of dissipation

∇ - Partial derivative

Δ - Variable difference

τ - Viscous stress component

Φ - Viscous dissipation term

CHAPTER 1

INTRODUCTION

1.1. Background

Appearance is as important as functionality and reliability in consumer product. It helps to determine success in capturing market share. Currently, trend shows that most of electronic devices will offer as many functions as possible but in a sleek and minimal form factor enclosure [1], [2], for example, as quoted by Ryan [1], a staff writer at www.inc.com, “the Apple iPhone, it is remarkably simple looking, for all it does”. Implementation of minimalism and simplicity in design makes it more challenging for designer to integrate aesthetic values and engineering aspects into one product together.

As a well-known fact, electronic devices rely on flow and control of electrical current to perform their function and whenever electrical current flows through resistive element, heat will be generated [3]. In ensuring reliability of a product throughout its designated life time, thermal management is an aspect that must be considered when designing an enclosure for the product because heat generation process is irreversible and generated heat must be removed to maintain continuous stable operation [4]. In most cases, the lower the temperature, provided the lowest device operating temperature is not exceeded, and the change of temperature with respect to time, the better they are [4].

Electronic devices cooling can be done in variety of ways. Pure conduction and natural convection are examples that commonly applied. In small form factor handheld devices, such as smartphone and tablet, radiation plays an important role in dissipating heat from device exposed surface [5]. Some devices however, due to its multi-functionality and complicated circuit board design, a more powerful cooling mechanism is required.

For a system of stackable electronic devices, development of centralized intelligent thermal management system that highly flexible and adaptable to increase or decrease in heat dissipation due to addition or reduction of equipment devices is a challenge. If successful, it helps to reduce waste in another area, such as electrical energy and malfunctioned cooling fan.

1.2 Problem Statement

How to construct a centralized thermal management system that able to transfer heat dissipated from multiple separated heat sources located inside electronic devices at different stacking level?

1.3 Research Questions

- Will air able to circulate through critical area inside each stacked electronic device with current design constraints?
- What is the effect of increase or decrease of cooling fan speed on local velocity magnitude and total temperature distribution inside equipment module?
- What is the effect of the increase or decrease in number of stacked device on total temperature distribution if cooling fan speed is constant?
- Is there any turbulence area that affects heat transfer performance?

1.4 Research Objectives

- To simulate heat transfer characteristic of air circulation inside system enclosure
- To validate mathematical model for simulation with results of analytical calculation and numerical solution of forced convection benchmark problem.
- To investigate effect of cooling fan speed against local velocity magnitude and total temperature distribution inside stacked equipment.
- To investigate effect of stacking level of electronic device against local total temperature distribution.

1.5 Research Scopes

- ANSYS Fluent will be employed to simulate air circulation
- Simplified geometry of components and casing shape as system boundary
- Enclosure material will be limited to thermoplastic normally used in industry, i.e. Acrylonitrile butadiene styrene (ABS), but to simulate the worst-case scenario of heat transfer from internal casing into environment, wall boundary condition will be set as adiabatic.

1.6 Significance of Study

The idea of Internet of Things (IoT), where devices are interconnecting each other while transferring information wirelessly, starts in early 2000. Since then, a lot of technologies have been developed and momentarily the trend shows that it will continue indefinitely now.

By sticking to modular concept in product design, product or system manufacturer will be able to adapt to new technology faster because half of product development process, i.e. the enclosure design, does not have to be started over from scratch. The whole system can be customized or updated based on latest technology and consumer needs. Indirectly, it helps to reduce electronic waste due to human desire to replace old equipment electronic system that does not up to date with latest technology.

Marketing of device with new technology is also at lower risk because if the introduction fails, the whole system can still be sold, but with current available devices. Another significant advantage is in manufacturing aspect, where devices with standardized enclosure will help manufacturer to reduce manufacturing cost because tooling cost will be considered one time only. Figure 1.1 gives a summary of advantages of developing such system.

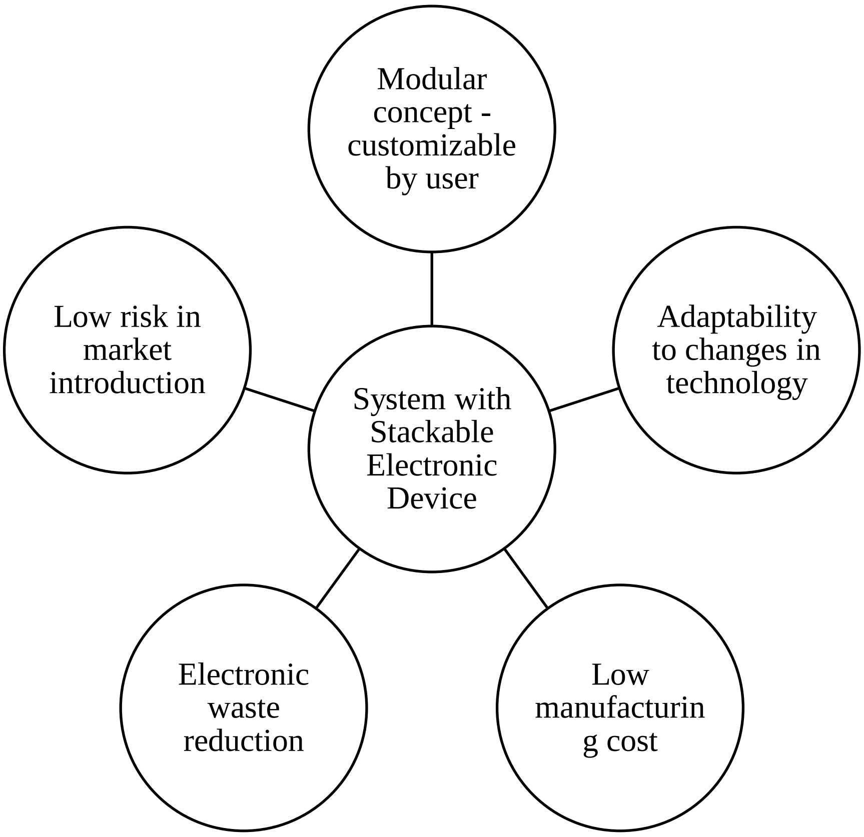

Figure 1.1: Significant of system of stackable electronic devices.

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