Designing Notebook Computers to Ensure a Comfortable User Experience: Effects of Surface Temperature, Material, Locality, and Ambient Temperature

Eric Baugh and Rina Doherty

Intel Corporation
2111 NE 25th Ave,
Hillsboro, OR 97124
United States
{eric.baugh,rina.a.doherty}@intel.com

Abstract. Two studies are described to determine the effect of locality, age, gender, ambient temperature, surface material and surface temperature, on user annoyance during a typing task on notebook computers. The studies were conducted in Oregon and Taiwan, using real computers modified with heaters under the keyboard and palm rests. Computer chassis made from both metal and plastic were studied, and users were exposed to ambient temperatures of both 23 °C and 35 °C. No practically significant effect of locality, age, gender, or ambient temperature was observed, but the ergonomic comfort between metal and plastic surfaces was very different at the same temperature.

Keywords: user experience, computer, temperature, comfort, annoyance.

1 Introduction

High performance mobile computing devices have many engineering challenges, one of which is the thermal design. A proper thermal design not only cools the internal components, but should also provide a safe and comfortable external surface for users. Currently, surface temperature safety limits governing information technology equipment (such as UL 60950 [1]) are very high and generally do not drive the thermal design of notebook computers. A recently published safety standard (IEC 62368 [2]) will impose lower limits, but there is still significant uncertainty as to the usage conditions to which it will apply and whether it will afford a comfortable user experience in and of itself.

Assuming that safety limits are met, the choice of an ergonomic limit involves many trade-offs, and not only along the cost/thermal performance axis. Different market segments, such as value and premium, might require different targets to meet customer expectations, and the same might apply to emerging markets versus developed markets. Notebook computers with metallic construction have a different aesthetic appeal than those constructed from plastic, but this must be balanced against the

A. Marcus (Ed.): Design, User Experience, and Usability, Pt II, HCII 2011, LNCS 6770, pp. 539–547, 2011.

different manufacturing costs of the two materials. The competitive landscape must also be considered. In order to effectively weigh these trade-offs, data is needed on the subjective impact of surface temperature.

The perception of comfort is subjective, and many factors might influence a user's response to heat. Could using a device in a hotter climate make a user more or less sensitive to the heat of a computer? Does gender or age play a role in heat sensitivity? Does the surface material of the device have an effect? Two studies were carried out to answer these questions. Both studies were designed to determine the influence of age, gender, locality, surface material type (metal and plastic), and ambient temperature (23 °C and 35 °C) on user annoyance of the top (typing) surface temperature of notebook computers.

2 Experimental Hardware

In order to provide a natural usage scenario, real notebook computers were modified with a mix of stock and custom foil heaters applied to the underside of the keyboard tray and the palm rests. An example of a modified system is shown in Figure 1. When an appropriate voltage is applied, the palm rests and the keys of the keyboard are brought to an elevated temperature, which is monitored by a thermocouple embedded in the center of the palm rest or attached to the underside of a key. Figure 2 shows an infrared image of a notebook computer with a plastic chassis where the palm rest heaters can be clearly seen. The heaters underneath the keyboard tray are not well defined because the tray acts as a thermal spreader.

The temperatures for the first study were established using an open-loop calibration procedure. The voltages necessary to attain each desired surface temperature in both ambient room temperatures were pre-determined in a laboratory before the experiment was conducted with the participants. While direct, this method has limitations on accuracy (due to differences between the laboratory conditions and the conditions during the actual experiment) and speed (because it may take a long time for the device to reach the desired temperature when driven at a fixed voltage). In order to overcome these limitations, a closed-loop control was implemented for the second study. This involved a PID (proportional plus integral and derivative) control program running on a master computer which monitored the actual temperature of each thermocouple in the experimental computers and adjusted the voltage in real time. This allowed the surfaces to reach the desired target temperature with a high degree of accuracy (within ±1 °C) in the minimum amount of time since large voltage swings were allowed initially when changing temperatures, and then the magnitude of the voltage changes were reduced as the system stabilized. Even with the closed-loop control system, however, the thermal inertia of the devices meant that about 10-15 minutes was required for stabilization at each new temperature.

In both studies, the voltage was held constant when the participants were using the computers. This replicates the constant power condition that a heavy workload would provide to the typing surface of the computer. Since conduction into the human hand is a more effective means of heat dissipation than the radiation and natural convection modes that a bare surface experiences, the surface temperature of the notebook will drop in the space of a few seconds when touched under normal conditions. The amount of temperature drop on contact is dependent on several things, including the pressure with which the hand presses and the amount of blood flow in the hand. Because there is no standardized way of testing the actual contact temperature, the values in this paper and those in the safety standards cited above represent the initial, pre-contact surface temperature.

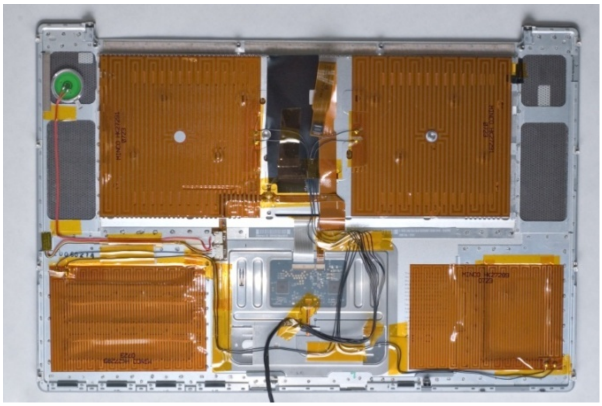

Fig. 1. Foil heaters applied to the underside of the keyboard tray (top row) and palm rests (bottom row) of a notebook computer with metal surface

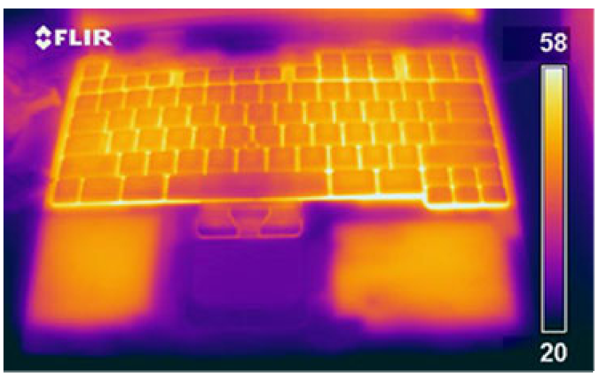

Fig. 2. Infrared image of a notebook computer with plastic surface when the underside heaters are activated. Temperature scale is in degrees Celsius.

3 Experimental Design

Participants between the ages of 18 to 50 years with an equal mix of men and women were recruited from the general public around Portland, Oregon and around Taipei, Taiwan. All participants used computers on a regular basis and did not employ a 'hunt and peck' style of typing (to limit the variability of surface contact during typing).

Since the medical literature indicates that diabetes can cause a loss of heat sensation (diabetic neuropathy [3]), this was also used as a screening criterion.

Tests were conducted in two ambient temperatures, 23 °C and 35 °C. The lower ambient was chosen to be consistent with the nominal temperature used for acoustic testing of information technology products [4] and represents a typical office or home environment in the United States of America. The higher ambient was chosen to represent a thermal stress condition. The studies were conducted in walk-in thermal chambers so that the ambient temperature could be controlled. Because one of the thermal chambers at the Oregon site was rather compact, participants at that site were also screened for claustrophobia. Randomization and counterbalancing techniques were used to reduce order effects for surface temperatures, material types, and ambient temperatures. For the first study, ambient temperature was a between-subjects variable, while for the second study it was a within-subjects variable.

Using a five-point rating scale as seen in Table 1, participants were asked to rate their annoyance level with respect to the warmth they felt from the keyboard and palm rests after two minutes of typing with the computer placed on a table. Annoying was defined as the extent to which the warmth or heat would bother, disturb, or disrupt them while carrying out the typing task. Participants repeated this task on several computers in order to be exposed to the full range of temperatures and material types. For the second study, the participants also changed between thermal chambers with different ambient temperatures.

Participant age, gender, and initial surface temperatures for the two studies are summarized in Tables 2-4. There is a good balance of ages and genders. The temperatures for the metal systems are generally lower than those for the plastic systems, reflecting the difference in expected user comfort given the respective material properties and the results of an informal pilot study. A narrower range of temperatures was used for the second study, based on the results of the first study and compensating for the increase in testing time by having ambient temperature be a within-subjects variable.

Table 1. Participant Rating Scale

Rating	Description	Interpretation
5	Perceptible but not annoying	Some warmth might be noticeable, but not uncomfortable and would continue to work
4	Perceptible and slightly annoying	Heat is noticeable, but not uncomfortable and would continue to work
3	Perceptible and annoying	Uncomfortable, but would continue to work
2	Perceptible and very annoying	Would continue to work only if highly necessary
1	Perceptible and extremely annoying	Intolerable for any length of time and would not continue to work

Table 2. Participant Gender Summary

Study	Total Participants	Male Participants (Portland/Taipei)	Female Participants (Portland/Taipei)
1	81	18/21	20/22
2	45	21/--	24/--

Table 3. Participant Age Range Summary

Study	Total Participants	Age 18-28	Age 29-39	Age 40-50
1	81	24	32	25
2	45	10	20	15

Table 4. Initial Temperature Summary

Study	Surface Material	Ambient (°C)	Initial Temperatures (°C)					
1	Plastic	23/35	41	45	49	53	56	59
	Metal	23	41	44	47	50	---	---
	Metal	35	---	44	47	50	---	---
2	Plastic	23/35	---	---	48	52	56	---
	Metal	23/35	40	44	48	---	---	---

4 Results

This section will review the observed locality, age, gender, material, ambient temperature, and surface temperature effects for user annoyance related to typing on a notebook computer. Participant ratings were averaged to form a mean opinion score (MOS).

4.1 Locality Effect

Only the first study was conducted in two localities, namely Portland having a moderate to cool climate and Taipei having a much warmer climate. Figure 3 shows the analysis of the overall locality effect, indicating that there is no statistically or practically significant effect. The same is true when each material type and ambient temperature is analyzed separately. This result should not be taken to suggest that there are never any geographic differences, but rather that any such differences may have more to do with the experience level of different regions with computers and the nature of the regional marketplace rather than strictly climatic variations.

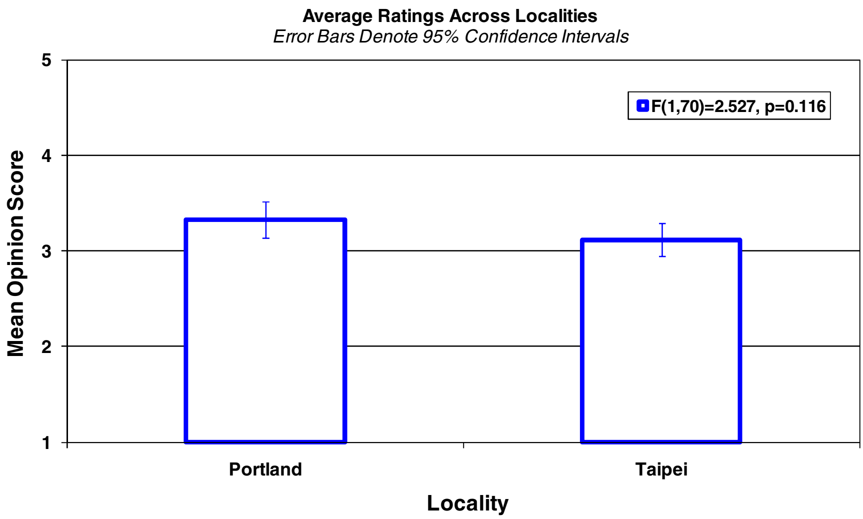

Fig. 3. Overall locality effect

4.2 Age and Gender Effects

Figures 4 and 5 show the overall analysis of the age and gender effects from the first study, indicating that there is no statistically or practically significant effect. The same is generally true when each material type and ambient temperature is analyzed separately, and for the second study as well, with the exception that the gender effect approached the threshold of statistical significance in some cases. However, in all cases the gender effect is small in practical terms, and it is recommended that as long as both men and women are included in a study then the result should be acceptable to either gender.

4.3 Ambient Temperature Effect

Figure 6 shows the analysis of the ambient temperature effect. This is a combination of data from the first and second studies. No temperature dependence is seen in the overall analysis. This is consistent with the fact that burn threshold data is independent of ambient temperature [5]. Medical literature also reports that average skin temperature is relatively insensitive to ambient temperature, changing less than 4.5 °C when the ambient temperature changes by 20 °C [6]. Given these findings, it is recommended that ergonomic limits be specified as fixed temperatures over the range of ambient temperatures studied, rather than as values relative to the ambient temperature.

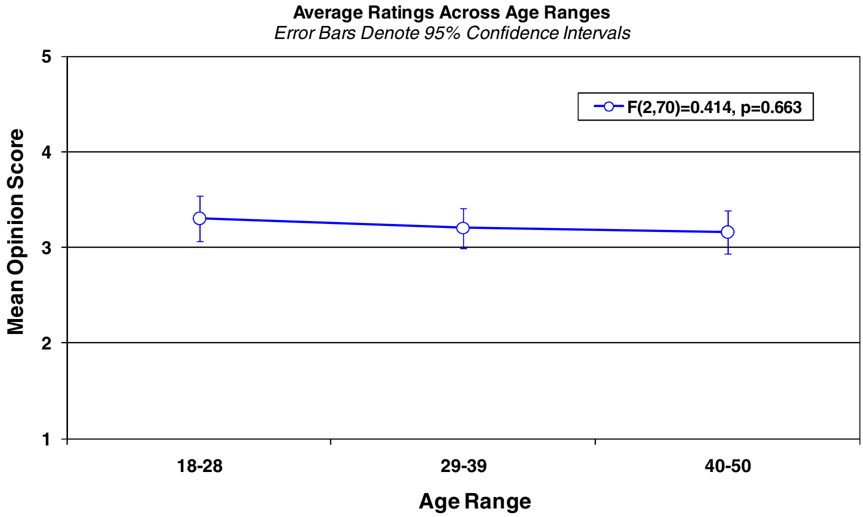

Fig. 4. Overall age effect from first study

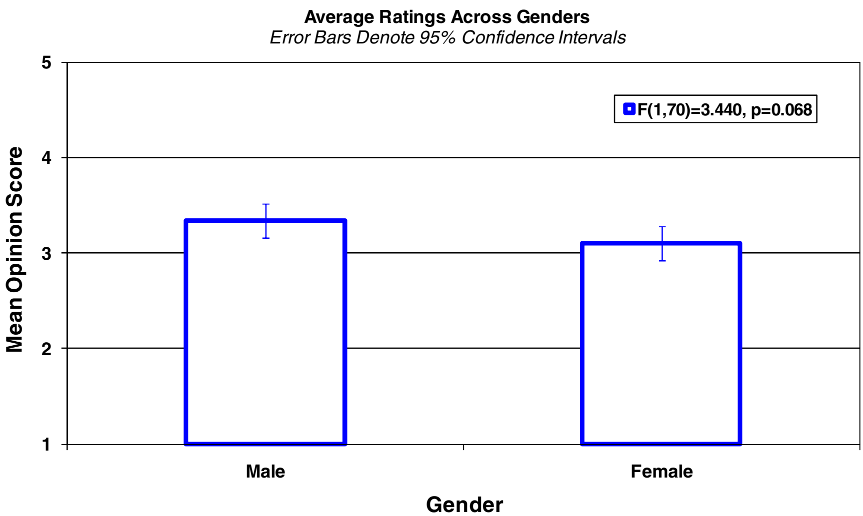

Fig. 5. Overall gender effect from first study

4.4 Material and Surface Temperature Effects

Figure 7 shows the analysis of the effect of the initial surface temperature for metal and plastic surfaces for the second study, which had more accurate starting temperatures due to the use of the closed-loop control system. For the plastic surface, the first and second points are not statistically different, nor are the second and third points. All three points for the metal surface are statistically different from each other. It can be seen that there is at least an 8 °C offset in the temperature between the two surfaces for the same mean opinion score (MOS), with the temperature difference increasing as the annoyance increases (MOS decreases).

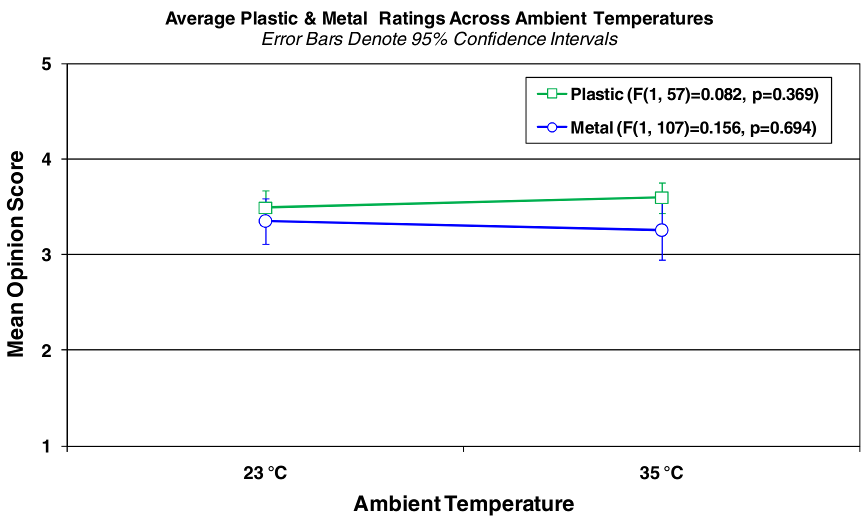

Fig. 6. Ambient temperature effect (selected data from first and second studies)

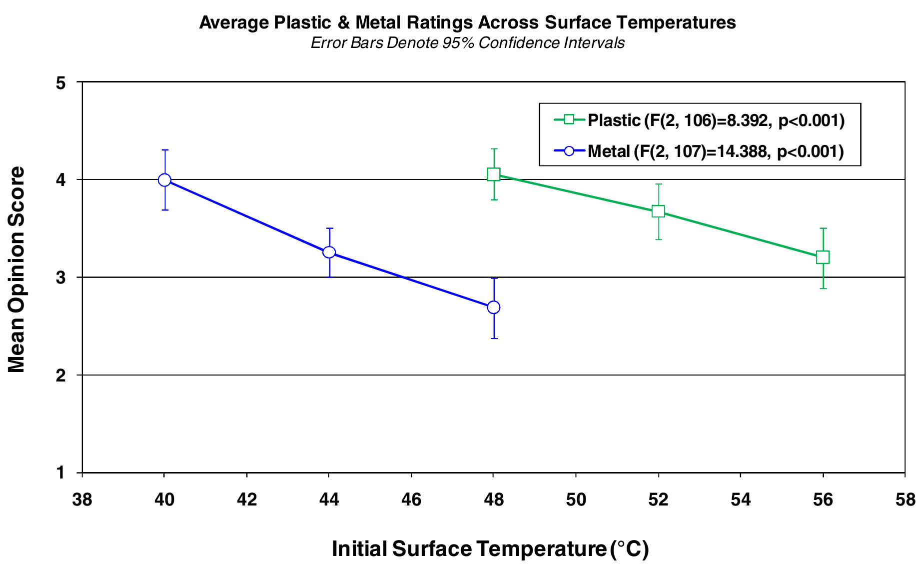

Fig. 7. Effect of initial surface temperature for metal and plastic surfaces (second study)

5 Summary

User comfort and industrial design are both important competitive considerations for notebook computer designers. The findings from these studies clearly show that users tolerate higher temperatures for plastic surfaces than metal surfaces. This must be weighed against the manufacturing costs of each material, the aesthetic appeal, and the cost of the required thermal solution. No dependence in practical terms on age or gender was observed, nor was any difference seen between users in a moderate climate and users in a warmer climate. However, this does not rule out geographic differences based on other factors. No dependence on ambient temperature was observed, and it is recommended that ergonomic limits be specified as fixed temperatures over the range of ambient temperatures studied, rather than as values relative to the ambient temperature. These studies are intended to provide system designers with reliable user perception data to assist them in making informed choices when selecting ergonomic targets for notebook computers.

Acknowledgements. The authors would like to acknowledge the contributions of Eric Salskov, Jessica Tabor, Samy Lin, and Justin Huttula for their help in the execution of these studies.

References

1. UL 60950 Safety of Information Technology Equipment, 3 edn. Underwriters Laboratories, Northbrook, Illinois, USA (2000)
2. IEC 62368-1: Audio/video, information and communication technology equipment - Part 1: Safety requirements, 1 edn. International Electrotechnical Commission, Geneva, Switzerland (2010)
3. Gelber, D.A., et al.: Components of variance for vibratory and thermal threshold testing in normal and diabetic subjects. J. Diabetes Complications 9(3), 170–176 (1995)
4. ECMA-74: Measurement of Airborne Noise Emitted by Information Technology and Telecommunications Equipment, 11th edn. Ecma International, Geneva, Switzerland (2010)
5. ISO 13732-1: Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces — Part 1: Hot surfaces, 1st edn. International Organization for Standardization, Geneva, Switzerland (2006)
6. Strigo, I.A., et al.: Effect of Ambient Temperature on Human Pain and Temperature Perception. Anesthesiology 92(3), 699–707 (2000)