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Experimental Validation of a Conceptual Vapor-based Air-conditioning System for the Reduction of Chip Temperature Through Environmental Cooling in a Computer Closet

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Abstract: This study proposed to manage the thermal environment of the interior space of a computer closet by totally lowering its cooling air temperature. In analogy to the air conditioner commonly used in routine life, a mesoscale integrated refrigerator was fabricated to regulate the environmental temperature inside the computer. Conceptual experiments on the prototype system were carried out. It was demonstrated that the surrounding air temperature in the computer could be lowered to about 32.7℃ from its original 54.7℃. Therefore, without changing any of the cooling components, an evident enhanced cooling effect for the computer system could be realized. The mesoscale air conditioner specifically developed for thermal management was economic and easy to operate, which would find significant applications in the computer industry. Just like the terminals in air conditioning systems, this integrated refrigerator could support many evaporators to removal the large amount of heat generated by multiple components. These evaporators could also be attached directly to the surfaces of chip devices such as central processing unit (CPU) and display card etc. to cool the temperature there. The present active cooling system is flexible in adjusting the local thermal conditions. For example, if two evaporators were used in the air-cooling system, one of them could be applied to cool the environmental temperature, while the other one attached to CPU directly. The concept given in this study is expected to provide a high performance cooling for the notebook PC, desktop PC and large computer. It can also be extended to more wide area involved with high heat generation rate.

Keywords: vapor compression system; integrated circuits; mesoscale air conditioner; liquid cooling; thermal management; chip cooling

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Nomenclature

A——Surface area of the fin base (m^2)
A_f——Section area of the fin (m^2)
b——Width of base (m)
C——Specific heat of fin material [J / (kg · K)]
C_p——Specific heat of water [J / (kg · K)]
h_f——Heat convection coefficient [W / (m · K)]
K——Thermal conductivity of fin material [W / (m · K)]
L——Fin length (m)
l——Fin height (m)
m——Mass of water (kg)
N——Total number of the fin
Q——Heat transfer rate between the fin and the surrounding environment (W)
q——Refrigeration capacity (W)
T——Temperature (℃)
T_0——Base temperature (℃)
T_f——Surrounding air temperature (℃)
t——Time (s)
U——Section perimeter of the fin (m)
U_1——Voltage across the heater (V)
U_2——Voltage across the fixed resistance (V)
W——Heat generation rate of CPU (W)
x——Coordinate (m)

Greek

α——Coefficient
ρ——Density of fin material (kg/m^3)
δ——Fin thickness (m)

1 Introduction

Over the past few years, CPU speeds kept being improved at a dramatic rate. In order to realize the new speed, CPU are assembled with more transistors, which are drawing more power and having much higher clock rates. This leads to an ever-larger heat produced by the CPU in the computer. Pentium-Ⅳ CPU and Athlon XP, released by Intel and AMD respectively, have high heat dissipation and therefore require excellent cooling performance. For example, 2GHz Pentium-Ⅳ processor made in 0.18μm manufacturing process has thermal design power (TDP) 75.8W, requiring cooling performance 0.47℃/W (@40℃). 2GHz Pentium-Ⅳ processor made in 0.13μm manufacturing process has a little lower TDP 52W and requires cooling performance

0.53℃/W (@ 40℃)[1]. The tendency for a rise in the CPU capacity resulted at present in increasing heat release to 50—100 W for desktop PC and to 20—35 W in notebook PC[2]. CPU heat sinks have been added to all modern PC CPUs to help alleviate some of the heat from the processor into the surrounding environment. But as the standard conduction and forced-air convection techniques no longer provide adequate cooling for sophisticated electronic systems, new solutions are being looked into liquid cooling[3], thermoelectric cooling[4-7], heat pipes[8], and vapor chambers[9]. Liquid cooling is a much more efficient way at drawing heat away from the processor and outside of the system. This benefits the system by allowing for higher clock speeds in the processor as the ambient temperatures of the CPU core are still within the manufacturer's specifications. This is the prime reason why many people tend to favor the use of liquid cooling solutions for their processors. However, generally there are two moving parts (impeller and fan) to a liquid cooling system. Both of them do need to run at very high speeds, which augment the amount of noise by the system. Furthermore, if the system is not properly installed, leaks could cause severe damage to the components inside the system. There is also the possibility of injuring to the individual installing the system into the computer. Solid-state thermoelectric devices have no moving parts, which is perhaps their most attractive virtues. Unfortunately, their relatively poor Coefficient of Performance (COP) limits them to low power applications. Furthermore, high power applications may require additional active cooling to remove heat from the rejection side of the thermoelectric device. A heat pipe is a condenser-evaporator system in a simple form as a hollow tube with layers of wire screens along the wall to serve as a wick. Heat pipe has an advantage that it has very low thermal resistance and its performance is relatively insensitive to its length. Consequently, it can be arranged in many shapes to accommodate different configurations. It has in fact been implemented in laptop computers. Whereas in the desktop server application, a flat type rectangular heat pipe is used to attach under the base of the heat sink to realize temperature uniformity across the heat sink base. This will reduce the spreading resistance in the heat sink base and therefore improve the heat sink performance. It should be noted that the heat pipe itself could not provide active cooling. It is, as a rule, only part of an integrated system, which ensures heat collection and sink may be equipped, for instance, with a fan.

As CPU heat dissipation has been on the gradual increase and computer has shifted toward being compact, all these solutions have limited cooling performance in an insufficient space. These conventional methods have either reached their practical application limit or are soon to become impractical for recently emerging electronic components. Therefore application of active cooling is considered as an alternative to these conventional methods seriously for cooling further high power processors[10-14]. Utilization of refrigeration as a viable cooling solution has been traditionally challenged by concerns such as system operating conditions and heat capacity, overall system efficiency, reliability, packaging, size and cost. Also, system RAS (reliability, availability and serviceability) is an issue of critical importance[10]. Vapor compression can lift large loads and make heat sink work at below ambient temperature. Vapor compression refrigeration offers several other important advantages. These include low mass flow rate, high COP, and the ability to transport heat away from its source.

In general, vapor compression systems are quite efficient, to some extent because of the isothermal heat transfer processes in the evaporator and condenser. The problem with applying vapor compression systems to electronic packaging is the difficulty in miniaturizing the system. There is one company, Kryotech, which markets a relatively small vapor compression refrigerator that can be incorporated to cool an AMD chip down to - 40℃[15]. However, this system is much larger than the mesoscale and microscale systems that are the focus of all the users, and is made to be installed below the tower of a desktop computer. A particular challenge to miniaturize the vapor compression refrigerator, and indeed to miniaturize all the refrigeration systems, is to make a small, yet efficient, gas compressor. Research is underway to develop miniature vapor compressors[11-12, 16], and to develop miniature gas compressors for application in these or other systems[17]. Unfortunately, up to now no system performance data are available yet. Thus, we fabricate an integrated refrigerator system to regulate the environmental temperature inside a computer[18]. The system reduces the heat sink surface temperature below ambient air temperature and makes the heat sink work at a much lower temperature. In analogy to the air conditioner commonly used in routine life, the integrated refrigerator also could support many evaporators to remove the large amount of heat generated due to multiple components. Further, to illustrate the wide applicability of the present integrated system, it was also suggested to serve as a liquid cooling source instead of the air-cooling system. Unlike the conventional liquid cooling, such liquid cooling system could maintain the CPU temperature below the ambient temperature. The focus of this study is restricted to refrigeration system that is used for cooling entire cabinets and can be incorporated into an integrated system.

2 Method and Principle

The main purpose of the vapor compression refrigeration cycle is to transport energy from the personal computer to be out of the system through the surrounding air. A schematic representation of the vapor compression cycle is given in Fig 1. The conventional vapor compression system consists of a condenser, expansion device, an evaporator and a compressor. A capillary tube was chosen as the expansion unit in this study. The system useed a fluid, to move heat from one place to another. Liquid refrigerant entered the indoor coil, operating as the evaporator during cooling. The liquid refrigerant absorbs heat as it changes state from liquid to vapor without changing its temperature. The vapor refrigerant was subsequently carried through the suction tube to the compressor, which was basically a pump that raises the pressure so it will move through the system. Once it past through the compressor, the refrigerant was said to be on the " high " side of the system. Then, it now flows into the refrigerant-to-air heat exchanger, operating as the condenser during cooling. After the refrigerant leaves the condenser, it reaches the capillary tube. The capillary tube allows the high-pressure refrigerant to "flash" through and thus becomes a cooled liquid with lower pressure. When pressure reduced, as with spraying an aerosol or a fire extinguisher, it significantly cools. The cycle is complete as the cool, liquid refrigerant re-enters the evaporator to pick up computer closet heat.

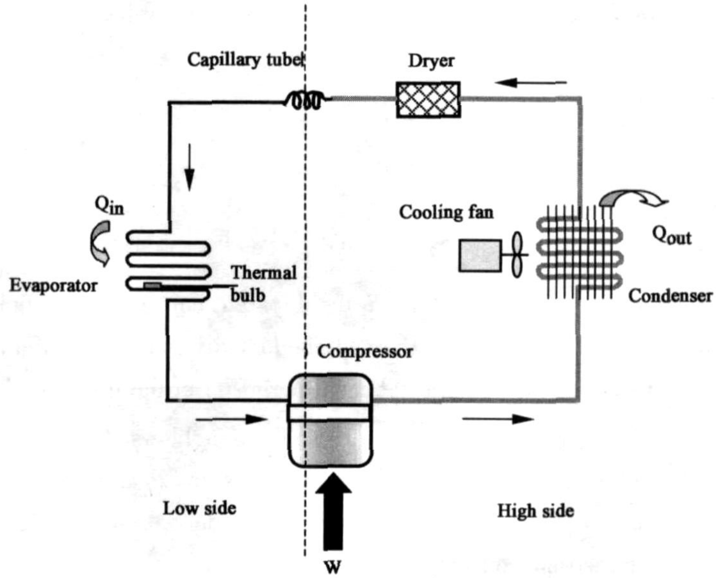

Fig 1 Schematic of refrigeration cycle

The primary objective of thermal management of computer system is to remove heat from the computer closet and to avoid triggering temperature-activated failure mechanisms. Conventional vapor compression cooling system should attach its evaporator to the surfaces of chip devices such as CPU. Due to space limitations in some computer closet, this method could not be widely applied. Based on currently existing technique, the vapor compression cooling system could be used just as a heat sink. The heat comes from the warm, most computer closet air blown across the evaporator coil. As it passes over the cool coil, it gives up some of its heat and moisture may condense. The cooler and drier air is re-circulated by a blower into the computer closet.

Vapor compression system offers several advantages for cooling the computer closet. It can reject heat far from the source by separating the evaporator and the condenser. Further, it transports large quantities of heat with a small mass of circulating fluid. These both are the advantages over the traditional liquid cooling. Vapor compression operates at a COP approximately three times that of thermoelectric devices in a similar application.

3 Theoretical Model

Unlike the traditional cooling ways such as improving performance of the heat transfer utilizing extended surfaces through the increased surface area, organization of the flow patterns to increase the film coefficient, and changing material of the fins, here we proposed to totally decrease the surrounding air temperature which would make the thermal management more flexible. The effect of these last three methods with constant surface area will be compared in concept for the same rectangular plate fin.

For a small control volume as illustrated in Fig 2, the energy-balance equation for the fin reads as

$$\frac{d^2 T(x)}{dx^2} - \frac{h_f U}{KA_f}(T - T_f) = 0 \quad (1)$$

or

$$\frac{d^2 T(x)}{dx^2} = m^2 (T - T_f) \quad (2)$$

where, T_f is the surrounding air temperature, h_f the apparent convection coefficient between the fin surface and the surrounding air, K the thermal conductivity of the fin material, $A_f = L \times \delta$ the sectional area of the fin, $U = 2(L + \delta)$ the sectional perimeter of the fin, L the length of the fin, δ the thickness of the fin, and $m = \sqrt{h_f U / (KA_f)}$. The fan blows these fins with a constant rotational speed. For simplicity, the surrounding air temperature T_f and the apparent convection coefficient h_f both could be considered as constant in the derivation. This kind of assumption could be accepted for forced-air convection in small space.

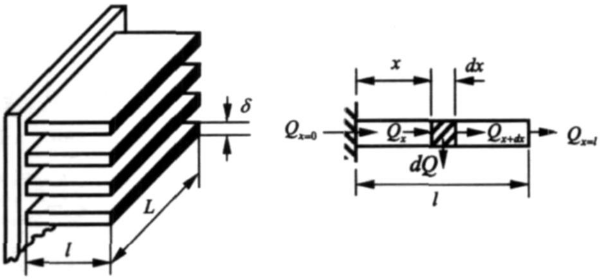

Fig 2 Heat transfer in rectangular plate fin

We define T_0 as the base temperature at the point of the junction between fin and the base. For the case in which the base temperature T_0 is specified, one boundary condition could be written as

$$T = T_0, x = 0 \quad (3)$$

For the case in which the fin is very long, i. e. , $l \gg \delta$, the heat flux at the fin tip approaches zero as x increases, the second boundary condition is thus written as

$$\frac{\partial T}{\partial x} = 0, x = l \quad (4)$$

where, l is the width of the fin. Solution to this model leads to

$$T = T_f + (T_0 - T_f) \frac{\cosh[m(l - x)]}{\cosh(ml)} \quad (5)$$

where, $\cosh(x) = \frac{e^x + e^{-x}}{2}$.

The heat transfer rate between the fin and the surrounding environment Q can be obtained as[19]

$$Q = h_f(1 - \Phi)A(T_0 - T_f) + N\sqrt{hUKA_f}(T_0 - T_f) \cdot \tanh(ml) \tag{6}$$

where, N is the total number of the fin, $A = L \times b$ is the surface area of the basement, b is the width of the basement, and the coefficient $\Phi = NA_f/A$, $\tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}}$.

In steady state, the heat loss from the fins Q will be equal to the heat generation rate W of the CPU, then the base temperature T_0 could be obtained as:

$$T_0 = T_f + \frac{W}{h_f(1 - \Phi)A + N\sqrt{hUKA_f} \cdot th(ml)} \tag{7}$$

The typical values are applied as given in [20]:

$T_f = 40$℃, $h_f = 50$W/m^2·℃, $K_a = 235$W/m·℃, $K_c = 410$W/m·℃,

$l = 3.5 \times 10^{-2}$m, $L = 1.08 \times 10^{-1}$m, $\delta = 1.5 \times 10^{-3}$m, $N = 12$, $W = 60.0$W,

$b = 5.0 \times 10^{-2}$m, $\rho_a = 8.96 \times 10^3$ kg/m^3, $\rho_c = 2.70 \times 10^3$ kg/m^3.

where, K_a is the thermal conductivity of the aluminum, ρ_a the density of the aluminum, K_c the thermal conductivity of the copper, and ρ_c is the density of the copper.

The improved performance of decreasing the surrounding could be evaluated by equation (7) theoretically. In the following section, the experiment will also be carried out to preliminarily understand the cooling behavior of the present thermal management strategy.

4 Hardware Fabrication

4.1 General

In this paper, an integrated refrigerator system was fabricated to regulate the environmental temperature of a computer. The "cooling engine" must be integrated or otherwise accommodated in the physical design. For the purpose of only testing the air conditioner concept for thermal management, the present vapor compressor had not been designed for aesthetics in our prototype. Clearly, it could be made much lighter and smaller than this under the consideration of industrial design[11, 16-17]. A wave like fined-tube heat exchanger was adopted as

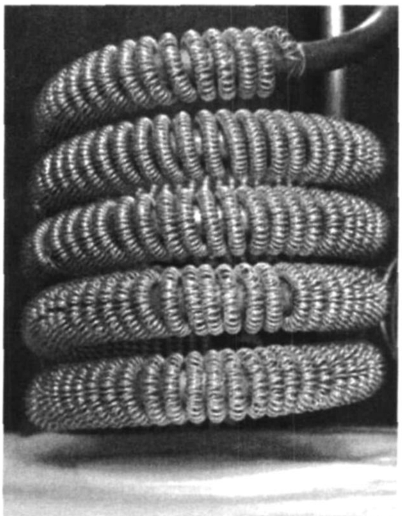

Fig 3 Evaporator made by copper tube coiled with small spring

the condenser in this prototype. The evaporator was made by copper tube coiled with small spring (shown in Fig 3), which created a cool surface to which heat may transfer from the air or liquid passing through it. The evaporator could be separated from the condenser and compressor. Thus the vapor compression system can reject heat far from the source. Filter is installed in the liquid line of the system after the condenser. Its construction is generally in the form of a tube, which contains coarse and fine mesh filters. These prevent foreign matter such as dirt, metal filings and carbon sludge from circulating with the refrigerant. The tube also contains a drying agent or dessicant, which will absorb any moisture in the refrigerant. R-134a was chosen for the present study which currently has been proven to be an environmentally safe refrigerant that is chlorine-free[21-23]. Refrigerant tubing must be incorporated into the physical design to supply or remove the refrigerant.

Every electrical installation must be protected from current overload. This is achieved by locating a protective device at the commencement of each circuit in the form of a fuse or circuit breaker. Water, a hazard to electronic devices, condenses on exposed surface at or below dew point temperature. This issue extends to all exposed cold area of the refrigerant path. Therefore cold surface must be insulated from and sealed against moisture-laden air to avoid hazardous condensation.

According to different cooling mediums, following a brief description of air and liquid refrigeration technology, emphasis will be placed on the analysis of air-cooling system.

4.2 Air-cooling system

Fig 4 is a schematic representation of the air-cooling system cycle. the computer closet from the inner of the evaporator through a plastic tube. At last, the warm air after heat exchange

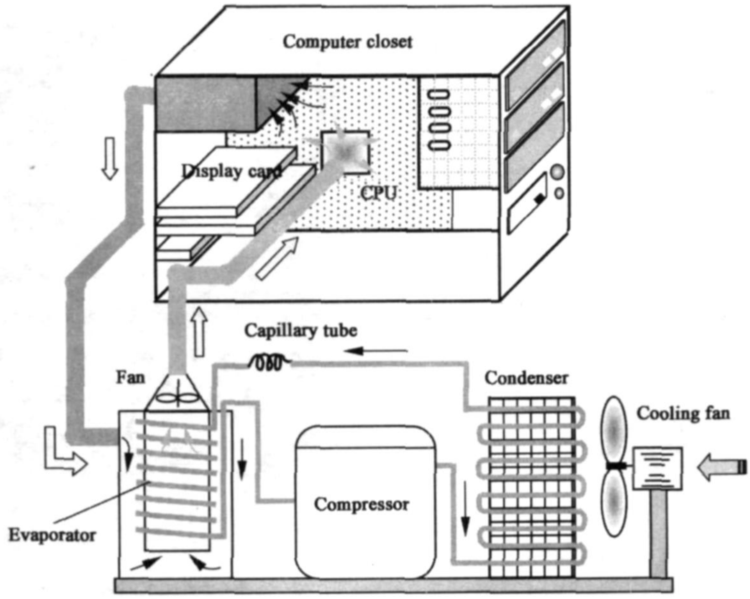

Fig 4 Schematic of vapor compression refrigeration

with the computer flew back to the evaporator's outer space to complete the cycle. This would lower the environmental temperature of the computer closet and reduced the heat sink surface temperature to below ambient air temperature. Fig 5 shows the prototype of the air-cooling system. This close cycle is beneficial in reducing the hazard of the condensed water on the cold surface.

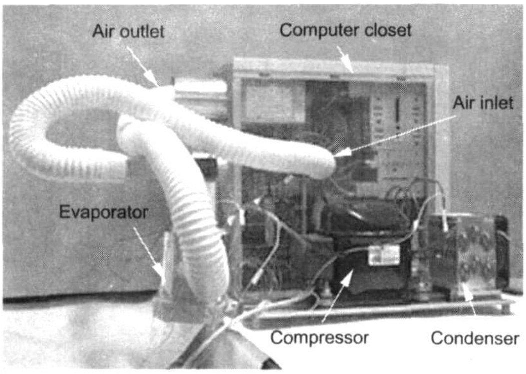

Fig 5 Prototype of air-cooling system

In analogy to the air conditioner used in the housing climate control, the integrated refrigerator also could support many evaporators to removal the large amount of heat generated due to multiple components. In this case, some of the evaporators could be attached to the surface of certain devices such as CPU and display card. The active cooling system would be flexible for adjusting the local thermal conditions. For example, if two evaporators were used in the air-cooling system, one of them can be applied to decrease the environment temperature, while the other one can be attached to cool CPU directly. It would strengthen the total cooling performance. With the advances in computer industry, this system is expected to be very useful in thermal management.

4.3 Liquid-cooling system

Fig 6 is a prototype of liquid-cooling modules. To compare it with Pentium-Ⅳ CPU boxed cooler, we used a 71mm ×47mm ×8mm heater to simulate the Pentium-Ⅳ CPU. There may be some difference between the heater used in the liquid-cooling system and the real computer chip. However, the heater could provide different uniform heat flux by flexibly adjusting the voltage applied on it. Therefore it can be applied to test more situations. Cold plate was placed above the heater, and thermally conductive silicone grease was filled between the heater and the cold plate in order to minimize the thermal resistance occurring in surface contact. Cold plate design must assure efficient thermal transfer from heater to the water inside the cold plate. Flat and smooth surfaces for the plates are generally required. The cold plate is fabricated from copper with thin wall design to shorten the thermal path from the target to the water.

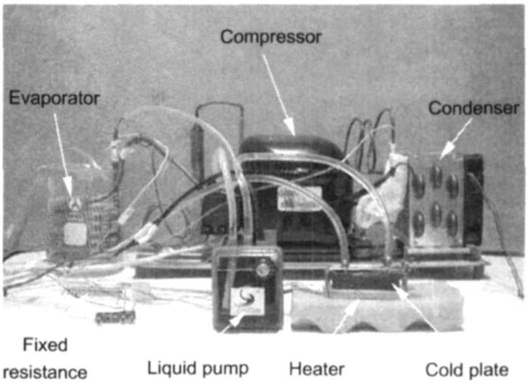

Fig 6 Prototype of liquid-cooling system

The evaporator of the refrigerator system was immersed into a beaker with 450 ml water. The water is subsequently carried through the suction tube to the water pump. Then the cold fluid passed to the cold plate. The heater released its heat to the fluid running across the cold plate as the water became into a warm liquid. The warm liquid then came back to the beaker finally. The cycle completes as the cold fluid passes to the cold plate.

If the system is not properly installed, leaks could cause severe damage to the components inside the computer. There is also the possibility of injuring to the individual installing the system into the computer. Water cannot usually be considered, both because of its ionic conductivity and its boiling point, 100℃, which is too high for maintaining CPU temperature below 85℃[13]. The widely studied alternatives to water are the dielectric fluorochemical coolants, FluorinertTM, manufactured by the 3M Company, which boil at 56℃ for FC-72[24]. In addition, application of vapor compression to personal computer requires careful engineering design. Cold surface cannot be allowed to collect condensate from the surrounding air. The entire solution must be cost effective and reliable.

4.4 Measurement system

In this study, an apparatus and experimental procedure have been developed to facilitate a systematic study of air conditioner for thermal management of chip cooling. The schematic diagram of the apparatus is given in Fig 7. The electrical current for the heater is controlled by regulated DC power supply WYK-605, whose working voltage range is 0—65V. The thermocouples are calibrated in the ice water and an accuracy of ±0.1℃ is obtained. The transient temperature and voltage across the heater are obtained using a 48 channels HP Agilent 34970 Data Acquisition/Switch Unit. The HP Agilent 34970 Data Acquisition/Switch Unit is connected with the personal computer with the data acquisition card (HP E2078, USA). The acquisition software uses HP BenchLink Data Logger, which can immediately display, analyze and save the input measurement data.

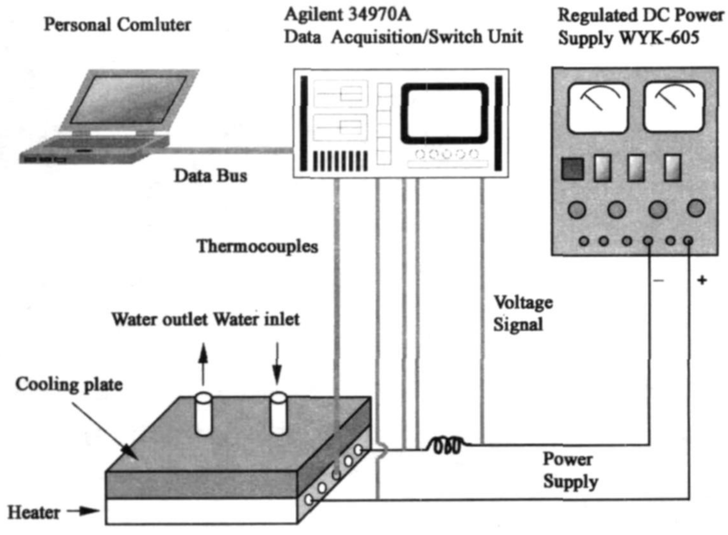

Fig 7 Schematic diagram of measurement on liquid-cooling system

The thermocouples were placed on the evaporator inlet, evaporator outlet, condenser inlet, condenser outlet and compressor to monitor the operational aspect. Another thermocouple was placed on the bottom of the CPU to evaluate the air-cooling performance. In the liquid cooling system the thermocouples were placed on the water outlet, water inlet and the middle of heater to evaluate the liquid cooling performance. The heater was made of 0.3 mm-dia nickel-chromium wire and its resistance was measured as 43.4Ω. The resistance of the fixed resistance was 0.5Ω. The voltage was changed after the temperature reached the steady state.

All temperature and voltages sampling were carried out with a Data Acquisiton / Switch Unit (Agilent 34970A, USA) and displayed at 2 s intervals by the computer.

5 Results and Discussion

For brief, the details of the performance of the vapor compression system, such as cooling capacity, refrigerant mass flow rates, compressor performance, cycle COP, etc are not measured in our study. All of these have been studied in other literatures[10]. The temperature of the computer chip is calculated and measured to explain the influence of varying environment temperature on CPU performance.

5.1 Refrigeration capacity

The cooling capacity of the system is a strong function of the evaporation and condensation temperatures, which will vary significantly from the liquid-to-refrigerant evaporator to the air-to-refrigerant evaporator. In this study, attentions were mainly paid to the temperature decrease of the computer chip. A simple experiment was particularly carried out to evaluate the cooling capacity. The evaporator of the refrigerator system was immersed into a beaker with 200 ml water. The evaporator releases its heat to the water. The temperature of the water then decreases gradually after the compressor begins to work (Fig 8). Ice rind appears at the evaporator inlet after three minutes. At 44 minutes, the evaporator turns out to be covered with ice and the temperature of evaporator outlet drops significantly, which means a strong cooling effect has been produced. At this time the water could not release its heat because of the huge thermal resistance between the evaporator and the water, which was caused by the ice. Overall, the temperature decrease of the water is about 14.7℃(ΔT) within 1200 s(Δt). The refrigeration capacity could then be obtained as:

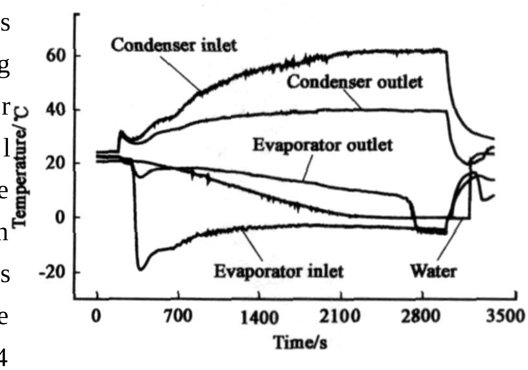

Fig 8 Refrigeration capacity of the vapor compression system

$$q = \frac{m C_p \Delta T}{\Delta t} \tag{8}$$

where, m is the mass of the water, C_p is the specific heat of water. Thus the refrigeration capacity in this test is estimated as about 102.4W.

5.2 Theoretical prediction

Decreasing the surrounding air temperature will significantly enhance the cooling effect by still utilizing extended surfaces or fins, although up to now it has not been paid with much attention. To determine the best heat sink design, we compared by equation (7) the thermal performances in three situations: different materials, different heat convection coefficients and different surrounding air temperatures. The heat sink base plate area, fin length, fin height, and fin center-to-center distance were 108mm ×50mm, 108mm, 35mm, and 1.5mm, respectively. As calculation shows, the copper heat sink gives out the lowest thermal resistance while the aluminum presents the highest (Fig 9). This behavior can be attributed to the higher thermal conductivity of the copper compared with that of the aluminum, resulting in lower thermal spreading resistance in the base, better heat conduction through the fins, and higher overall heat transfer to the ambient air. Fig 10 illustrates the influences of the heat convection coefficient on the temperature distribution in the fin of copper heat sink. The base temperature only reduced 3.6℃ when the heat convection coefficient changed from 50W/(m^2·℃) to 70W/(m^2·℃). However, the base temperature would reduce 10.0℃ when the surrounding air temperature changed from 40.0℃ to 30.0℃ (shown in Fig 11). This may imply that reducing the heat sink surface temperature would significantly improve cooling effect, which will be validated through experiment in the following.

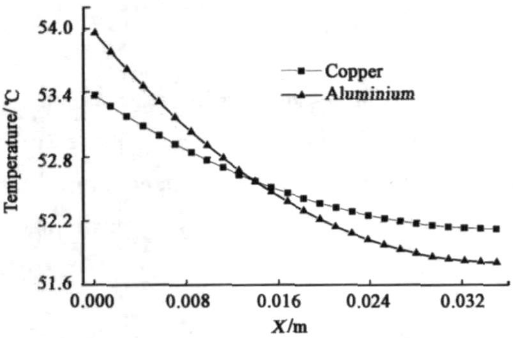

Fig 9 Influence of different materials to the temperature distribution in heat sink [h_f = 50W/(m^2·K), T_f = 40℃]

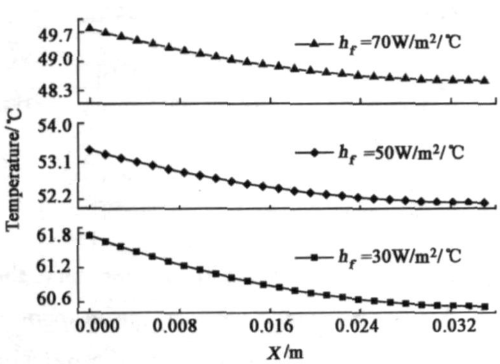

Fig 10 Influence of heat convection coefficient on the temperature distribution in the fin of copper heat sink (T_f = 40 ℃)

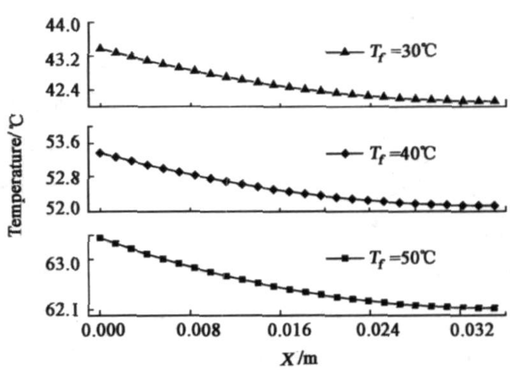

Fig 11 Influence of surrounding air temperature on the temperature distribution in the fin of copper heat sink [h_f = 50W/(m^2·K)]

5.3 Experimental tests

Cold air was pumped into the computer closet from the lateral hole, in which the cold air blew across the CPU directly. Fig 12 shows the cooling process when the distance between the CPU and the plastic tube outlet was 12cm. The initial air temperature in the computer closet is about 25.8℃. The temperature of CPU increased gradually when it was assigned to run a FORTRAN program. At 28 minutes, the cooling fan began to work and then enhanced the convection heat transfer in the computer closet. The temperature of CPU decreased from 54.6℃ to 51.0℃ due to the application of this fan. The vapor compressor began to work at 34 minutes. The temperature of CPU reached its steady state at 75 minutes and changed from 54.6℃ to 32.7℃. It has fallen 21.9℃ within 41minutes.

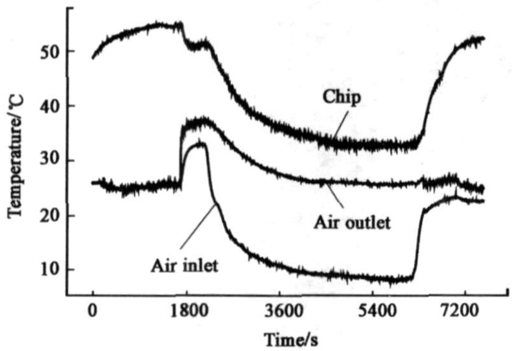

Fig 12 Temperature of CPU when the cold air entered the computer closet through its lateral hole

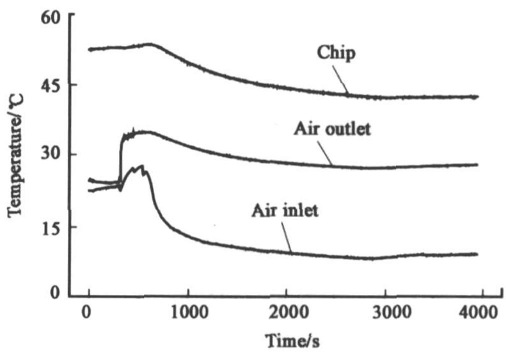

Fig 13 Temperature of CPU when the cold air entered the computer closet through its back hole

The cold air could cool the CPU directly when it entered the computer closet through the lateral hole. However this may make the computer users change their computer lateral cover. It was desirable to still use the present cooling air conditioner without changing the cover structure. In fact, for many computer closets, there were holes in the backside under the electrical source. The cold air could then be ventilated into the computer closet through them. In this case, the temperature of the CPU changed from 53℃ to 42.3℃ (Fig 13). But if certain fine plastic tubes were used to transport the cooling air directly to the specific object, more powerful cooling effect can be realized as desired.

Air-cooling system is very useful to lower the environmental temperature and reduce the heat sink surface temperature below the ambient air temperature. Except for this, the other type of cooling modules was also given in this study. The evaporator of the refrigerator system was immersed into a beaker with 450 ml water. The heater released its heat to the fluid across the cold plate. The initial temperature of the heater is about 25.9℃. The temperature of heater increased absurdly before the liquid pump worked at 6 minutes. With the conventional liquid cooling method, the heater temperature increased gradually. We let the vapor compression system to operate at about 21 minutes. The heater will reach 52.53℃ when its heating power is applied as 83. 1 W and it was cooled by cooling fan and heat sink with boned fins (shown in Fig 14). In the same situation, the heater will be cooled to 8. 02℃ using the liquid cooling system (shown in Fig 15). It indicated that liquid cooling system is an effective way of cooling small heat sources In addition, this means that with liquid-cooling system, convective heat fluxes of several hundred watts can be transferred from CPU without overheating the devices

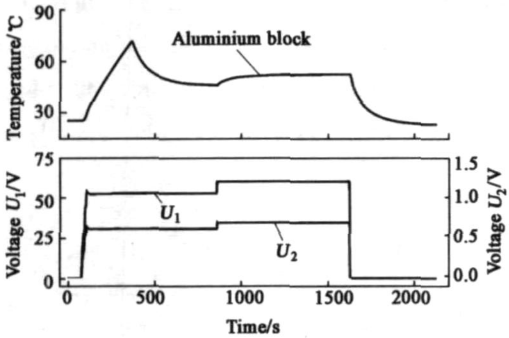

Fig 14 Temperature of heater cooled by cooling fan and heat sink with boned fins

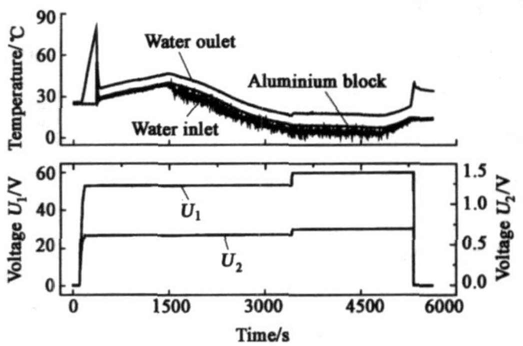

Fig 15 Temperature of heater cooled by liquid cooling system List of figure captions

Conventional liquid cooling is realized through pool boiling, forced convection, impinging jet, channel flow boiling, or other approach[13]. Perhaps the major weakness of them, in addition to the limited choice of liquid available for use in electronic packaging, is not being able to maintain the CPU temperature below ambient temperature. The liquid cooling system given in this study has conquered this problem to some extent

6 Conclusion

Today, the rapid development in information technology (IT) such as internet requires that PC should be capable of processing more data and more quickly. However, conventional cooling methods have their shortcomings Combining cooling fans and heat sinks has limited cooling capacity, and heat pipes contain undesirable working fluids that may leak and contaminate the computer components To overcome this problem, a high-performance, vapor compression refrigeration system is described and demonstrated in this study. A mesoscale integrated refrigerator was fabricated to regulate the whole thermal environment of an internal space with high heat generation such as in a computer closet The system successfully reduces the surface temperature of the heat sink to below the ambient air temperature. It was shown that the environmental temperature in the computer can be lowered to about 32. 7℃ from its original 54. 7℃ The present system can be flexibly applied to many thermal managements situations for chip cooling Further, as an alternative to air-cooling, liquid cooling based on the present cooling source was also tested Unlike conventional liquid cooling system, the liquid cooling system presented in this study is able to maintain the CPU temperature below ambient temperature. A series of experiments were further performed on the computer to validate these methods. If designing the present integrated refrigerator by various configuration sizes, the concept proposed in this paper is expected to provide a high performance cooling for the notebook PC, desktop PC and super computer.

Naturally, broader use of this powerful cooling technology depends on several factors. The first of all is the size, cost, weight and capacity of the vapor compressor. The effort made by the University of Central Florida[11, 16-17] is targeting a system, based on a centrifugal compressor, which would be about 7.5cm in diameter. The vapor compressor's size could be much smaller than that used in this study. On the other hand, vapor compression refrigeration system is one of the highest efficiency refrigeration systems. At last, the developing history of the vapor compressor is very long and the manufacturing technology has been already very ripe. It could run with high reliability and low cost. These warrant the future applications of incorporating the present system to thermally managing the computer closet, either in large or small scale.

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一种新型芯片冷却构思的实验研究
——利用蒸汽压缩空调系统降低计算机机箱环境温度以冷却芯片

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摘 要

提出通过降低计算机机箱内整体冷却空气温度达到热管理. 类似日常生活用的普通空调，提出一种整体式中尺度空调系统来调节计算机内温度，并在实验原型上做了大量概念性的实验. 结果表明，计算机机箱内环境空气温度可以从 54. 7℃降低到 32. 7℃. 说明此种方法可以在不改变计算机任何部件的情况下大大提高计算机系统的冷却效果，为热管理设计的这一特定中尺度空调机非常经济且易操作，在计算机产业上将会得到广泛的应用. 如同空调系统的末端一样，此整体式空调机可同时拥有多个蒸发器以带走多个发热元件产生的热量；蒸发器还可以直接扣在中央处理器 (CPU)和显卡等芯片的表面以冷却芯片. 本文提出的主动冷却系统在调节局部热环境时可灵活调整. 例如如果空气冷却系统中有两个蒸发器时，就可用一个冷却机箱内环境温度，另一个直接扣在 CPU 上. 本文提供的概念有望为个人笔记本电脑、台式机和大型计算机提供一种高效的冷却方法，也可应用在其他产热率较高的很多场合.

关键词：蒸汽压缩系统；集成电路；中尺度空调机；液冷；热管理；芯片冷却