Performance assessment of an indoor LED illumination incorporated with the building environment control system

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ABSTRACT

The target of this study is to investigate an innovative indoor LED illumination that uses heat pipes as the heat transfer channels to conduct the released heat of the LED to the heat-sink fins on the two sides. Natural convection inside the flow channels within the heat-sink fins or the forced convection made by the returned flow of HAVC system serve as the overall heat elimination mechanism. The released heat of the LED light can be successfully brought to the ceiling space or HVAC evaporator to ensure normal operation of the LED light and maintain a good life. Fundamental investigation of the heat transfer were carried out to assess the lighting performance and heat management of the indoor LED illumination, incorporated with the building environment control system.

Keyword: LED, heat pipe, building environment control, Green Building

1. INTRODUCTION

1.1 LED (Light Emitting Diode)

An LED (Light Emitting Diode) is a component made of a p-n interface diode as a light emitting subject. The emitted light includes the spectrum of infrared rays, visible rays and ultraviolet. The light emitting principle of an LED is, with forward biased, to enable electrons and electron holes to go through a depletion region into p type and n type areas respectively to generate recombination with another carrier, which releases energy in the form of light and heat during recombination.

1.2 Application of white light LED on building environmental control (room lighting)

White light LEDs are energy-saving light sources. Compared with incandescent tungsten lamps or fluorescent lamps, LED light boasts advantages of

(1) small volume, (digital) combination of multiple pieces and multiple kinds
(2) low power consumption, low voltage, low electric current initiation at around 1/8 of incandescent lamps or 1/2 of fluorescent lamps
(3) long life for over 10,000 hours, around 10 times of that of fluorescent lamps
(4) quick response and operation under high frequency: LEDs only need 100ns (nanoseconds) to respond, much quicker than 100～300ms (milliseconds) of regular incandescent lamps.
(5) environmentally friendly, quake proof, crash proof, recyclable without pollution
(6) flat package available to be developed into light, thin short and small products.

LED lamps are free from the disadvantages of high power consumption, and fragility of incandescent lamps and mercury pollution of fluorescent lamps. LED lamps have the potential to replace traditional lighting products in the future.

In addition to the advantages mentioned above, another application of LED under focus in building environment control (room lighting) is multiple colors of LEDs. With it, one can express the interaction among lamps, people and space. Lamps will no longer only have changes in shapes. Their rich, brilliant colors will also bring people delight and warmth. Designers can break away from the shapes of lamps and, with multiple colors of LEDs, convey the meanings of colored light to users to create different atmospheres of the room lighting environment.

1.3 Thermal solution of LED applications

As mentioned earlier, energy is released in the form of light and heat during the recombination of electrons and electron holes inside an LED. Traditional lighting LED products have smaller light efficiency and less released heat. There is no issue of heat emission. Introducing LEDs to regular lighting will make LED emitting lumen achieve the lighting standard. Currently, high brightness LED lumen exceeds 30 lumens. Application in lighting requires no less than 60 lumens. With the improvement of white light LED efficiency, the possibility of application in lighting is greater. Obviously, drive voltage of a single white light LED is low. It is not likely to have single crystal white light LED for lighting under current packaging. There are two solutions: (1) combination of crystal LED light sources and (2) using a large crystalline grain process to make it larger (0.6 ~ 1 mm^2) than regular crystalline grains (0.3 mm^2). Either way requires releasing extremely high heat in a tiny LED packaging. Without effective emission of such heat, light emitting efficiency of high bright LED will be reduced. Components are easily destroyed. Removing the heat from LED components is the main issue in LED lighting technology. (Hwang *et al.*, 2004b) (Park *et al.*, 2004).

Overall, effective thermal system design with dependable LED thermal performance is more important than a single crystal packaged LED's thermal performance (Kim *et al.*, 2003) (Hwang *et al.*, 2004a). The goal of this study is, with appropriate heat transfer channels combined with integrated operation of building environment control, to effectively remove the heat of the developed room lighting LED lamps to maintain lighting quality and life of products.

1.4 Heat Pipe as a heat transfer channel

The heat pipe concept was first brought forward by Gauger (1944), although it was not put into practice. In 1963, Grover (1966) first filed for the patent of an "Evaporation-Condensation Heat Transfer Device", heat pipes were then put into practice. Based on different structures of buds, heat pipes can be divided into wicks and thermal siphons. The two are devices transmitting a great amount of heat with the latent heat of different working flues in phase changes.

Wick structure heat pipes are divided into: (1) airtight containers, (2) capillary structures (wick structure) and (3) working fluids. Airtight containers must withstand the maximum vapor pressure from the operation of the heat pipe. Wick structures offer the channels to working fluids backflow on capillary power, which frees heat pipes from extra power. In Fig. 6, when one end (evaporation end) of the heat pipe is heated, the heat will vaporize the working fluids close to the pipe wall. The vapor pressure, of the heated end, is increased, making vapor flow to the lower pressure end (condensation end) to generate a vapor flow. The vapor releases its latent heat and condenses into liquid at the condensation end. The liquid inside the wick structure returns to the evaporation end through capillary power to complete a cycle. In this process, outside power is not needed. Latent heat from phase changes will complete transfer of heat, making a great amount of heat transmission possible.

Currently, researches on discrete point sources of heat pipes and performance of flat heat pipes are not available.

2. RESEARCH METHOD

2.1 Experiment model development and design

This study utilizes white light LEDs (Fig. 1) to replace traditional fluorescent lamps. Module innovative design can replace T-bar room lighting equipment (Fig. 2) used in offices, libraries, classrooms, and hospitals, etc. At the moment, only 15~20% of input power of LEDs is transferred for lighting; close to 80~85% input is transferred to heat loss. Provided such heat cannot be emitted from the LED itself, the junction temperature of LED chips will be too high, affecting light emitting strength and life. Thermal management needs to be considered in the application of LED in lighting equipment. White light LEDs and heat emission requirements will be integrated to form room lighting equipment to be placed in common rigid frame ceiling systems. The following is the idea of experiment model development:

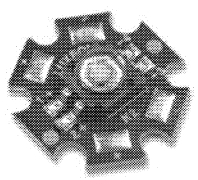

Fig. 1 White light LED

Fig. 2 T-bar room lighting equipment

Lumens of LED illumination must achieve the lighting standard in room lighting. The experiment uses 36 x 3W white light LEDs to meet lumen requirements. In consideration of heat dissipation, 4 heat pipes are installed for heat transfer as well as a part of the lighting equipment. Each flat heat pipe is attached with nine 3W white light LEDs. Those LEDs can be regarded as discrete point-heat-sources. On the two sides of the heat pipes are 6 fins for heat dissipation. Pitch between fins is adjustable. In prototype development, the pitch is 0.9 cm and the overall is in Fig. 3. This structure can be installed in a common rigid frame ceiling structure (as in Fig. 2). In accordance with repetition principle and reasonable boundary conditions, this study has 1/4 of the prototype as the target. It is called *experiment model* as in Fig. 3.

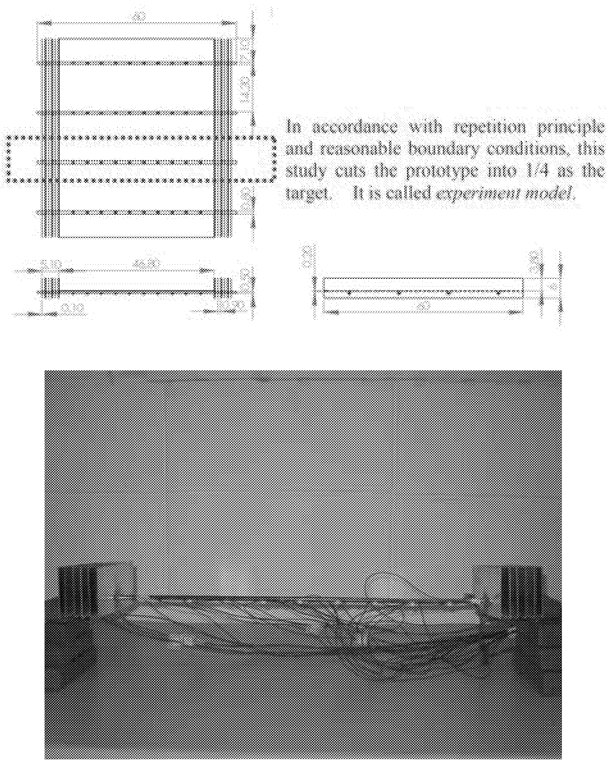

Fig.3 Prototype of LED lighting equipment for room lighting (unit: cm)

At turning on lighting, LEDs emit a great amount of heat, forming a heat source that must be released. Heat pipes are used as the heat transfer channels to convey the released heat of the LED to the heat-sink fins on the two sides. Natural convection around the heat-sink fins or the forced convection made by the returned airflow of HAVC system serves as the overall heat elimination mechanism. The released heat of the LED light can be successfully brought to the ceiling space or HVAC evaporator to ensure normal operation of the LED light and maintain a good life. (as in Fig. 4)

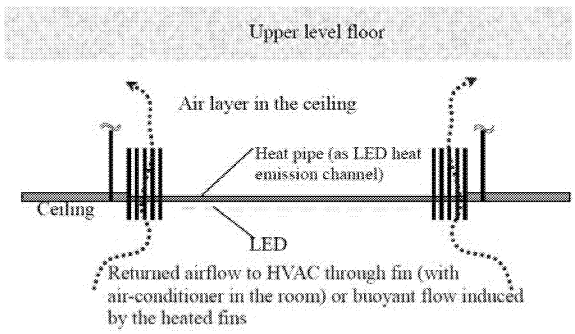

Fig. 4 Integration of room LED lamp and building environment control system

The LED crystalline grains used are white light 3W LEDs (domestic and Lumileds products). The heat pipes are made locally. The heat pipe wall is copper; the wick structure is a copper groove. Original pipe diameter is 8 mm. To have an appropriate paste surface of LED crystalline grains, a small amount of cold rolling is applied onto the cylinder heat pipe. Pressed flat, the heat pipe height is 3 mm and 5 mm with a length of 600 mm, as in Fig. 5. The internal working fluid is pure water. Evaporation section is 46.8 mm long; condensing length is 10.2 mm.

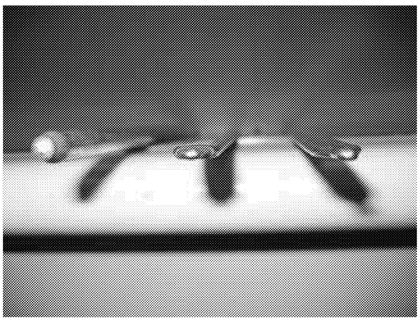

Fig.5 Heat pipes used in this study

Heat emission paste is laid on the surface between LED crystalline grain and heat pipe. The purpose of heat emission paste is to stuff the gaps between surfaces among each component in the heat emission module to reduce the contact thermal resistance and enhance heat emission performance. The heat conduction coefficient K of heat emission paste is 4.18W/m·K for a temperature between 0 and 170℃.

To quickly remove the heat from LED crystalline grain, heat emission fins are added on the two sides of the heat pipe to emit the heat to the air layer inside the ceiling with natural convection or forced convection. The heat, with returned airflow and forced convection, returns to FCU or AHU; in natural convection (no air-conditioning), the heat will be stored in the air layer of the ceiling to be removed by ceiling ventilation.

2.2 Explanation of experiment apparatus system

The experiment apparatus system is as Fig. 6. The inclination angle of experiment model is changeable. The angle is set at 0 (horizontal). The two sides are connected to an environment control chamber (heat convection boundary condition) and ceiling space simulation system. The two systems can be separated from the experiment model to form a free condition. In Fig. 16, experiment model ❶ (the LED lamps developed in this study) is connected to a heat exchanger. The environment control chamber ❷ is an air circulation device, offering heat convection boundary conditions. Constant temperature, Tr, and fixed wind velocity, Vr, simulate different indoor thermal environment to analyze influences of different environmental condition (i.e. air condition of returned airflow) on thermal performance of the experiment model; the ceiling simulation system ❸ is in an adjustable height structure. Entrance temperature of the environment control chamber (T), airflow rate ($\dot{m}$), and temperature of ceiling space (T) have to be measured. A heat flow meter and a thermal couple ❹ are installed along with the thermal flow direction. The thermal couples are placed at the socket of the LED, along the heat pipe and on heat emission fins. Data from the thermal couples and anemograph will be transmitted to the computer for storage through a data logger❺.

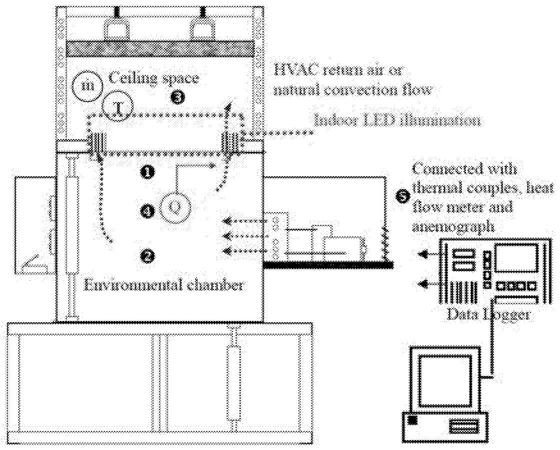

Fig. 6 Experiment facilities

2.3 Measuring factors and measuring locations

The major measuring factors and locations include: return air temperature and airflow rates of the environmental chamber; airflow temperatures at the ceiling space and within fin channels. Thermal couples are installed in the same direction as the thermal flow along the heat pipe, at the LED crystalline grain socket, fin socket, fin tip, top floor bottom and inside the top floor. A heat current meter is placed at the fin socket closest to the heat pipe. Data from the thermal couples and anemograph will be transmitted to the computer for storage, via the data logger. Flow structure of the air gap is observed via the measurement of airflow speed and tracer gas technique. Omega T-type (PR-T-24) thermal couples are used in this experiment.

3. RESULTS AND DISCUSSION

3.1 Comparisons of heat transfer performance of regular copper pipe and heat pipe

To begin, a round groove heat pipe, of 600 mm long and 8 mm in diameter is roll pressed into a rectangular heat pipe, 5 mm high. A 3 Watt LED is attached on the right side of this rectangular heat pipe and an 8 mm diameter hollow copper pipe (for comparison) respectively as the heat source. Nothing covers the heat pipe and copper pipe, making the two free thermal conditions. Thermal couples are evenly installed at the bottom of the heat pipe and copper pipe to observe the heat conduction. The results (Fig. 7) show that the rectangular grove heat pipe's steady state max. temperature is 39℃; the max. temperature of the hollow copper pipe is as high as 55℃. From Fig. 7, one learns that heat pipes can better distribute the heat evenly to the entire heat pipe while a hollow copper pipe fails to conduct well the heat source to the other end. Surface temperatures of heat pipe and copper pipe are distinctively different.

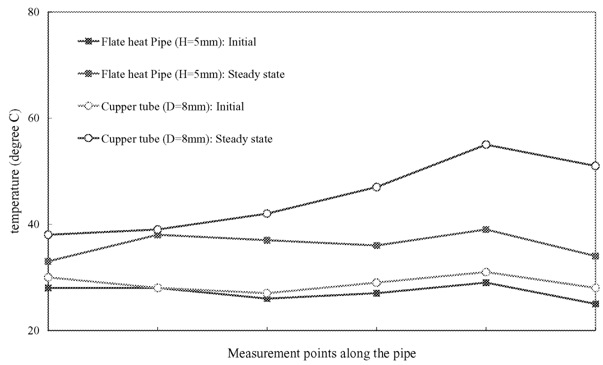

Fig. 7 Comparisons of heat transfer performance of regular copper pipe and heat pipe

3.2 Heat transfer performances of heat pipe with different pressed heights

This study presses flat the round groove heat pipe, which is 600 mm long and 8 mm in diameter, into rectangular groove heat pipes of 3 mm and 5 mm heights. 3 LEDs are applied at the same distance from the center of the two rectangular heat pipes as light (heat) sources to observe heat transfer. In Fig. 8, one can see the differences of the temperature distribution of the two heat pipes. The highest temperature of the 5 mm high rectangular heat pipe is 67℃, while that of the 3 mm high heat pipe is 74℃. Although the two heat pipes distribute heat to the two sides, due to different heights, vapor flows are affected, making flatter heat pipe have larger thermal resistance.

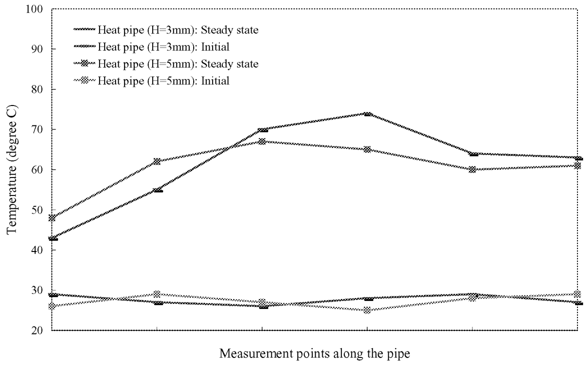

Fig. 8 Heat transfer performances of heat pipe with different pressed heights

3.3 Heat transfer performance of LED illumination incorporating heat pipe

Nine 3W LEDs are placed at the same distance in the middle of a 600 mm long and 3 mm high rectangular heat pipe. Thermal couples are applied evenly to observe temperature changes. As shown in Fig. 9, with natural convection mechanism, the highest temperature of the mid-section heat pipe can be 60℃ in evenly distributed heat temperature without distinctive highs. With a breeze set under air conditioning air return system (v=1m/s), the heat source highest temperature is reduced to 42℃ or 18℃ lower than that in natural convection conditions; later, the air return is set at a high gale (v=2m/s), there is hardly any difference in temperature compared to the breeze condition.

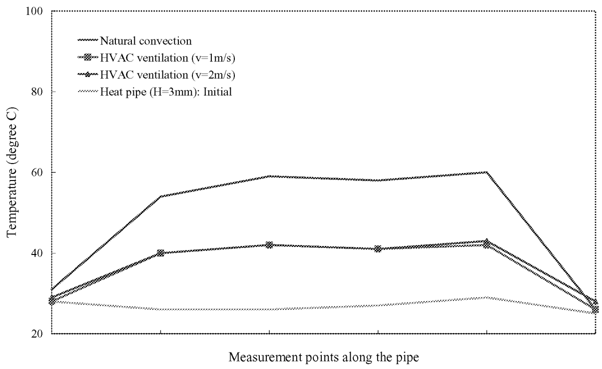

Fig. 9 Heat transfer performance of LED illumination incorporating heat pipe with different forced convections

4. CONCLUSION

The target of this study is to investigate an innovative indoor LED illumination that uses heat pipes as the heat transfer channels to conduct the released heat of the LED to the heat-sink fins on the two sides. Natural convection inside the flow channels within the heat-sink fins or the forced convection made by the returned flow of HAVC system serve as the overall heat elimination mechanism.

Heat pipes can better distribute the heat evenly to the entire heat pipe while a hollow copper pipe fails to conduct well the heat source to the other end. The 5 mm high flat heat pipe can perform better than the flatter (3 mm high) heat pipe. With natural convection, the highest temperature of the mid-section heat pipe can be 60℃ in evenly distributed temperature without distinctive highs. With a breeze set under air conditioning air return system, the heat source highest temperature is reduced to 42℃; later, there is hardly any difference in temperature compared to the breeze condition.

ACKNOWLEDGEMENTS

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