We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter 4

Heat Pump-Based Novel Energy System for High-Power LED Lamp Cooling and Waste Heat Recovery

Jiwen Cen, Zhibin Li, Yiwei Wang, Fangming Jiang, Shaoxiong Liao and Fuwen Liang

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78322

Abstract

Unlike incandescent light bulb, which radiates heat into the surroundings by infrared rays, light emitting diode (LED) traps heat inside the lamp. This fact increases the difficulty of cooling LED lamps, while it facilitates the recovery of the generated heat. We propose a novel energy system that merges high-power LED lamp cooling with the heat pump use; the heat pump can cool the LED lamp and at the same time recover the waste heat. In this way, a high percentage of the energy consumed by the LED lamp can be utilized. In this work, we developed a prototype of this energy system and conducted a series of experimental studies to determine the effect of several parameters, such as cooling water flow rate and LED power, on the LED leadframe temperature, compressor power consumption, and system performance. The experimental results clearly indicate that the energy system can lead to substantial energy savings.

Keywords: LED, heat pump, heat recovery, cooling, energy saving

1. Introduction

Light emitting diode (LED) is a promising solid state light source due to its high energy efficiency, eco-friendliness, small volume, long lifetime, quick response, low driving voltage, and good structural integrity. Compared with traditional incandescent light bulbs, an LED lamp only needs 10–20% of electric power to produce the same luminous flux [1].

LED is a cold light source, in which a photon is emitted when an electron transits from a high energy band to a low one inside LED. The wavelength of the emitted light is determined by the energy gap of the light emitting semiconductor material; it is usually fixed at a certain visible

IntechOpen

© 2018 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

light wavelength, which does not include the infrared range, while the light of the incandescent light bulb includes a wide range of wavelengths including visible light and infrared rays. Therefore, the heat generated inside LEDs cannot be radiated outside by infrared radiation as it occurs with the incandescent light bulb. So far, the luminous efficiency of LED is only about 20–30%. The remainder of the power input, about 70–80% in total, is eventually converted into heat. If the heat is not dissipated timely, the LED temperature will quickly rise. Once the pn junction temperature reaches its maximum allowed temperature, which is typically around 150°C, LED will burn out. In industry experience, LED will work efficiently when its leadframe temperature is below 60–70°C.

The major disadvantage of LED is its inability of radiating the generated heat; therefore, effective cooling measures should be taken to guarantee the expected life time of the LED. In the open literature, different cooling approaches to improve LED lamp performance have been reported. In the marketplace, traditional LED lamps dissipate heat into ambient air [2–17]. For example, Dong et al. [2] performed numerical simulations to determine the influence of heat sink design on LED lamp thermal dissipation; their specific aim was to optimize the number of fins and thickness of the heat sink. They found that these two parameters were key parameters for the shape and mass of the heat sink in practical applications. Tang et al. [3] developed a novel columnar heat pipe leadframe for a high-power LED device. They demonstrated that the luminous efficacy of the LED device with the columnar heat pipe leadframe is 19.2% higher than that with the conventional copper leadframe. Deng et al. [4] proposed an active cooling solution using liquid metal as the coolant for high-power LED lamps. They found that liquid metal cooling is a powerful way to dissipate heat from high-power LED lamps, and the fabrication of practical liquid metal cooling devices is feasible and their use is promising. Lin et al. [5] conducted an experimental study to investigate the heat transfer characteristics of an aluminum plate oscillating heat pipe (OHP), which consisted of parallel and square channel arrangements. Their experimental results indicate that the temperature of the LED decreases significantly while being cooled by natural convection when a plate OHP was used in the LED heat sink. Dong et al. [6] developed a heat sink with ionic wind for LED cooling. Their experiments and computational fluid dynamics (CFD) analysis confirmed the advantages of the heat sink with ionic wind for LED cooling. Wang et al. [7] also suggested using a needle-to-net type ionic wind generator based on corona discharge for high-power LED cooling. Their experimental results indicate that the designed ionic wind generator had good cooling performance close to cooling fan, coupled with lower energy consumption and less mechanically induced noise. Yung et al. [8] studied the thermal performance of a high-brightness LED array on printed circuit board (PCB) under different placement configurations. They proposed a new LED placement configuration to lower the individual LED temperature in the array by 26°C. Park et al. [9] developed an LED downlight consisting of a chimney and a radial heat sink. They concluded that installing the chimney can improve the heat sink cooling efficiency by up to 20% as compared to the installation of the hollow cylinder heat sink. The same team investigated an inclined cross-cut cylindrical heat sink in an attempt to improve the energy conversion and management of LED light bulbs [10]. They showed that when the fins had an angle of inclination of 25–30°, the thermal resistance was the lowest. However, the cooling performance decreases when the angle of inclination is greater than 50°. Xiao et al. [11] developed an automatic cooling device for

http://dx.doi.org/10.5772/intechopen.78322

thermal management of high-power LEDs. The device consists of a microcontroller, heat pipes, and a speed adjustable fan. The thermal resistances R_{sa} (from the heat sink to the ambient) and R_{ja} (from the LED chip to the ambient) of the cooling system operating at 12 Ware 0.37 and 5.95°C/W, respectively. The total power consumption of the cooling system is less than 1.58 W. Sömen et al. [12] studied by using ANSYS CFX 14 software the cooling effects of fin design, fin material, and free and forced convection on the junction temperature of automotive LED headlights. They presented a new methodology for defining the optimum cylindrical fin structure, and they also indicated that as the ambient temperature increases, especially in high-power LED lights, proper fin usage becomes essential. Jeng et al. [13] systematically studied the heat transfer characteristics of a porous green building material and the enhancement of LED lamp heat sink when LED lamp is inserted into this porous material. They demonstrated that the closed-cell aluminum-foam ceiling did help in the cooling of LED lamp. Wu et al. [14] designed a phase-change material (PCM) base heat pipe heat sink (PCM-HP heat sink) that consists of a PCM base, adapter plate, heat pipe, and finned radiator. The results show that the heat sink possesses remarkable thermal performance owing to the reduction of the LED heating rate and peak temperature and an excellent antithermal-shock capacity. Sufian and Abdullah [15] reported the enhancement of the heat transfer in high-power LEDs by a combination of piezoelectric fans and a heat sink. The results showed that the dual fans enhanced the heat transfer performance by approximately 3.2 times, while the quadruple fans enhanced heat sink of the LEDs by 3.8 times compared to natural convection. Zhao et al. [16] presented a study of the thermal performance of conventional plate-fin heat sinks and novel cooling device integrated with heat conductive plates (HCPS) for the application in high-power LED headlight. The results showed that the thermal performance of the heat sink with HCPS is better than the one only with the heat sink cooling system. Kang et al. [17] investigated a new cooling method of ethanol direct-contact phase-change immersion cooling in the thermal management of high-power LED. The experimental results showed that the ethanol phase-change immersion cooling is an effective way to make sure high-power LED work reliably and high efficiently.

In all the above mentioned approaches used for LED cooling, heat is simply dissipated with no further usage. Taking into consideration the influence of this heat dissipation on the surroundings, Ahn et al. [18, 19] proposed a new methodology to integrate LED lighting with heating, ventilation, and air conditioning systems to prevent this heating buildup in buildings. The heat sinks of LED lamps are placed inside the ventilation ducts; therefore, most of the LED heat is removed to outdoors by the duct air flow, avoiding in this way a further increase of the building thermal load.

An advantage for LED is related to being a cold light source, which offers the potential of heat recovery; as already mentioned, unlike incandescent light bulbs, which transfer heat into the surroundings by infrared radiation, LED traps heat inside the lamp if no efficient heat dissipation device to help it, which facilitates its recovery. However, the heat removal and recovery should proceed in such a way that maximum allowable temperature is not reached. If the aim is to use this heat for higher temperature applications, then the heat pump is the appropriate device.

In this paper, an integrated system combining a high-power LED lamp with a heat pump is proposed to simultaneously cool down the LED lamp and provide hot water using the LED waste heat. This approach allows that most of the electric energy consumed by the LED be

utilized, which greatly improves the energy efficiency. This combined system can be used to reduce building thermal load as indicated in the work by Ahn et al. [18, 19]. In addition, it is particularly suited to the scenarios that both high-power light and hot water are needed. For example, in railway station halls, airports, theaters, and sport stadiums, not only sufficient illumination is needed, but also a great amount of warm water is needed for sanitary.

2. Experimental prototype

Schematic of the experimental setup is shown in **Figure 1**, and the photo of the actual experimental setup is shown in **Figure 2**. The experimental prototype of the integrated system mimics a high pole LED lamp.

This system consists of an LED lamp acting as an evaporator for a heat pump, a regulator for oil returning, a compressor, a condenser, an expansion valve, and some connecting pipes. The structure of the lamp (or evaporator) is a hermetic hemisphere of 420 mm in diameter, which is made of stainless steel. The "opening" of the hemisphere is facing upward, and six equidistant round openings with a diameter of 38 mm are made on hemisphere surface with their centers at a vertical distance of 160 mm from the top plane. These round opening apertures are capped by the LED modules, which are tightly sealed by flanges and seal rings to keep the system hermetically sealed. In this arrangement, heat from the LED modules is transferred by pool boiling of the refrigerant inside the evaporator.

For experimental convenience with different LED power values, the LED modules are replaced with six aluminum blocks with inserted cartridge heaters; in this way, the heat inputs can be

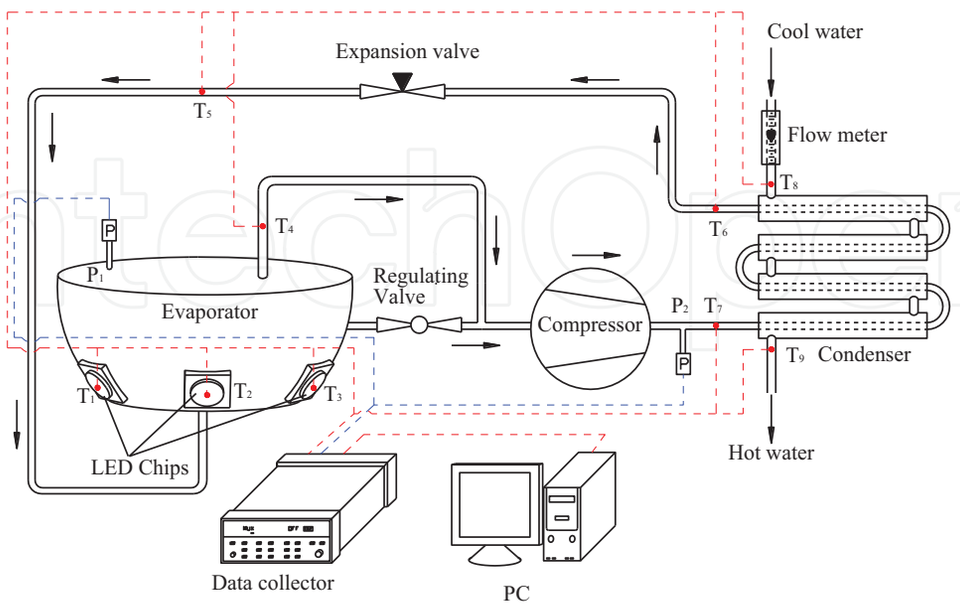


Figure 1. Schematic of the experimental setup. Dashed lines indicate the data acquisition connections; T denotes the temperature measuring point and P the pressure monitoring point.

http://dx.doi.org/10.5772/intechopen.78322



Figure 2. Photo of the experimental prototype.

easily controlled and measured. All surfaces of the system components, including the lamp and pipes, are wrapped with plastic insulation foam for thermal insulation.

Model number of the compressor is Hitachi SL242CV-C7LU with a rated power of 1150 W. It is an invariable frequency compressor. Further system improvement should be considered to use a variable frequency compressor with an inverter. The condenser is a double-pipe coaxial heat exchanger produced by Hangzhou Shenshi Energy Conversion Technology Co., Ltd. Its model number is QH2P286254. The diameter of the outer tube is 38 mm and inner tube 22 mm. Total heat exchange surface of the condenser is about 1 m^2, and water flows through the inner tube of the coaxial heat exchanger and R22 refrigerant flows through the annular region. A needle valve serves as the expansion valve of the heat pump. All the heat pump components are connected with 8 mm diameter pipes. Here, it has to be point out that R22 is going to be phased down and other new environmental friendly refrigerants, such as R410A, R290, R134A, R407c, R717, CO_2, etc., should be adopted. But which refrigerant is the most suitable for the heat-pump-based LED heat recovery system is further needed to be investigated. In this paper, R22 is used to build a base line system for future new refrigerant comparison because R22 is one of the most commonly used refrigerants in the past several decades.

The temperature at several points of the system is measured with K-type thermocouples with an accuracy of ±0.3°C. High-side and low-side pressure of the heat pump system are measured with pressure transducers model MB300,with a measuring range of 0–5 MPa with an uncertainty of ±0.2% full scale (FS), produced by Nanjing GOVA technology Co., Ltd. Temperature and pressure signals are collected by an Agilent data acquisition system and then transferred to a computer for further data processing. The water flow rate in the condenser is measured using a rotameter with an uncertainty of ±1% FS, in the range of 0–0.4 l/s. The

compressor power consumption is measured by a digital power meter in a range of 0–12 kW, with an uncertainty of ±1% FS. The calculated relative uncertainty range of coefficient of performance (COP) is approximately ±5%. Measurement points T_1–T_3 are LED leadframe temperature, T_4 is evaporator outlet temperature, T_5 is evaporator inlet temperature, T_6 is condenser outlet temperature, T_7 is condenser inlet temperature, T_8 is water inlet temperature, T_9 is water outlet temperature, P_1 is evaporator pressure, and P_2 is condenser pressure.

The working principle of the integrated system is as follows: refrigerant with quality close to zero flows through the expansion valve and enters the LED lamp, which serves as the evaporator for the heat pump. In the evaporator, the refrigerant evaporates, while it absorbs heat from the LEDs. The LED lamp is kept at the appropriate temperature by regulating the expansion valve. The refrigerant in vapor phase leaves the evaporator and enters the low pressure side of the compressor; at the exit of the compressor, the refrigerant is in the superheated state at relatively high temperature and pressure. The refrigerant then passes through the condenser, where it releases heat to the coolant (water). The cooled down refrigerant leaving the condenser enters the expansion valve, completing in this way a cycle. In reality application, a hot water tank should be used in case that hot water demand (e.g., domestic hot water needs) may be consistent with LED cooling demand.

In this work, as already mentioned, the LED lamp in the experimental setup is designed for a high pole LED lamp, a type of lamp typically encountered in large squares, harbors, and airports. In the present experimental setup, the quantity of refrigerant charged into the system should be sufficient to have the back sides of the LED modules fully immersed in the liquid refrigerant, when the system is operating at steady state conditions. In this way, effective heat transfer from the modules to the liquid refrigerant is guaranteed. The outlet of the evaporator is on the top side of the lamp (evaporator), where the refrigerant in vapor phase accumulates. However, during the operation compressor, oil contaminates the refrigerant in the liquid phase by floating on it and/or by mixing with it. To partially overcome this problem, an oil outlet was located approximately close to the level of the liquid refrigerant surface inside the evaporator; the flow rate of the oil coming through the outlet is controlled by a regulating valve. There are two modes to control the valve. The first is to open the valve constant at an appropriate small opening. The second is to open the valve intermittently. The primary aim of this valve is to prevent that too much liquid refrigerant flows out of the evaporator and two much oil accumulate inside the evaporator.

3. System performance evaluation

In the integrated system of LED lamp and heat pump, the LED leadframe temperature and the heat pump COP are the parameters of primary concern in the performance evaluation.

The COP of heat pump is defined as,

$$\mathrm{COP} = \frac{Q_{water}}{W_{comp}} \tag{1}$$

http://dx.doi.org/10.5772/intechopen.78322

where Q_{water} refers to the heat removed by the water flowing through the condenser, and W_{comp} refers to the power consumption of the compressor. Consequently, to conduct a parametric analysis, we investigate the effect of heating power and water flow rate on the performance of the integrated system. The heating power varies in the range of 1400–2400 W, which corresponds to the heat generation of LED lamps rated at approximately 2000–3400 W power, which are typical values for high-pole LED lamps. The water flow rate passing through the condenser is in the range of 0.020–0.240 kg/s; these flows are sufficiently small to produce relatively high-temperature water, which can be used as domestic hot water, while maintaining the temperature of the LED lamp with relatively minor variations.

The heat transferred to the water, Q_{water}, is calculated by using the following relation:

$$Q_{water} = c_w \dot{m}_w (T_{w_out} - T_{w_in}) \tag{2}$$

where c_w refers to the water specific heat, $\dot{m}_w$ refers to the water mass flow rate, T_{w_out} refers to the water outlet temperature, and T_{w_in} refers to the water inlet temperature.

Based on the energy balance for the compressor with the assumption the process is adiabatic, the refrigerant mass flow rate, $\dot{m}_r$, is determined as follows:

$$\dot{m}_r = \frac{W_{comp}}{h(T_{c_in}, P_c) - h(T_{e_out}, P_e)} \tag{3}$$

where T_{c_in} refers to the refrigerant temperature at the condenser inlet, T_{e_out} refers to the refrigerant temperature at the evaporator outlet, P_c and P_e refer to condenser and evaporator pressure, respectively, and h refers to refrigerant specific enthalpy determined for the specified state (T,P).

Compressor specific power consumption SW_{comp} is defined as

$$SW_{comp} = \frac{W_{comp}}{\dot{m}_r} \tag{4}$$

The influence of the water flow rates on the LED leadframe temperature is reported in **Figure 3**. By increasing the water flow rate, the temperature of the LED leadframe experiences a slight decrease. This observation is consistent with the heat rate of the condenser, which is constrained by the refrigerant side heat transfer coefficient; therefore, although higher water flow rates yield higher water side heat transfer coefficients, the impact on the overall heat transfer coefficient is of no great significance. Consequently, the temperature of the LED leadframe varies accordingly. This characteristic of the integrated system should be seen as an advantage, considering that a severe escalation of LED temperature will not occur when it is required high-temperature water at reduced flow rate.

Figure 4 reports the water temperature at the condenser outlet as a function of mass flow rate and heating power. As expected, with the increase of water flow rate, the outlet temperature decreases, and eventually with further increase of the flow rate, it would tend to the value of the water inlet temperature. From this figure, it can be observed that at the lower end of the

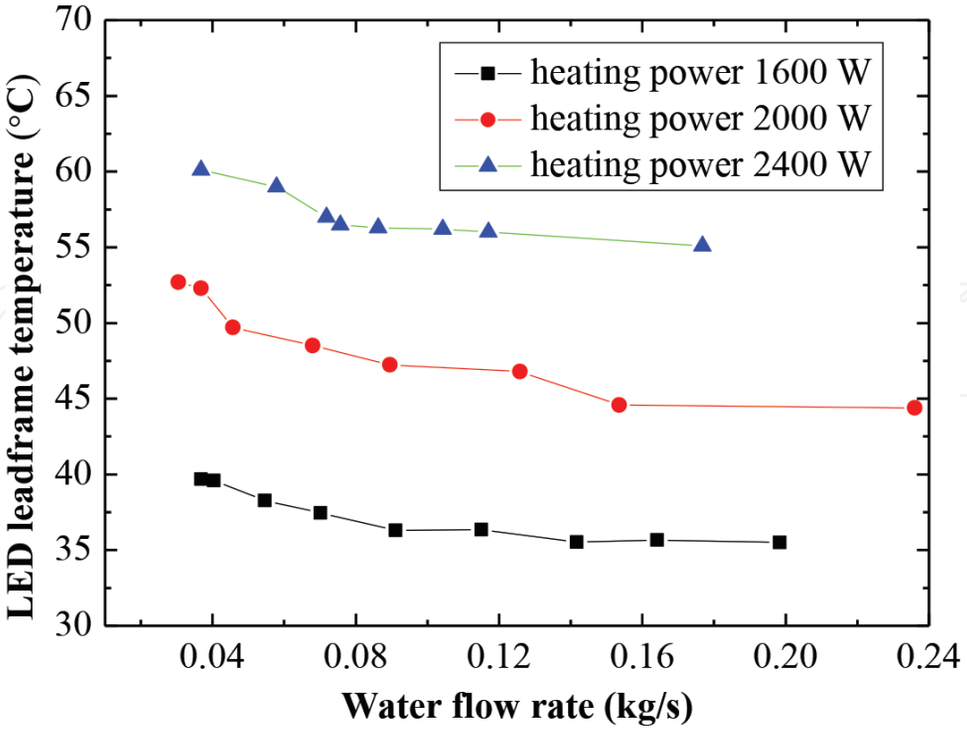


Figure 3. Temperature of the LED leadframe for different rates of water mass flow and heating power.

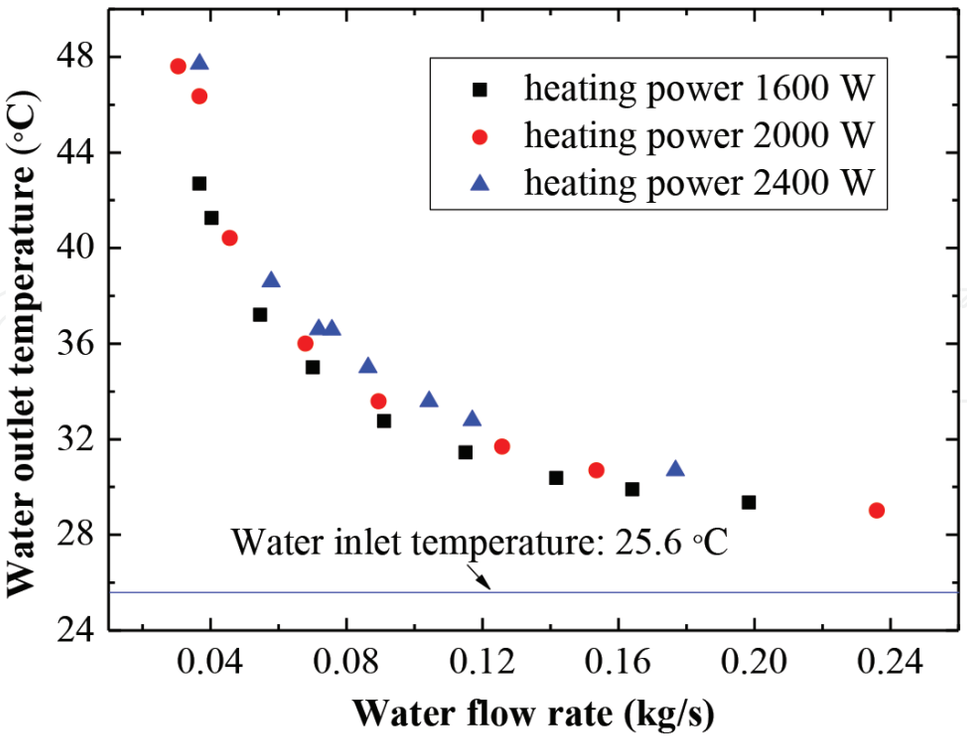


Figure 4. Water outlet temperature as a function of the water flow rate and heating power.

mass flow rates tested, the water outlet temperature can reach temperatures of 48°C; not surprisingly, for the tested higher water flow rates, the increase in the temperature from the inlet to the outlet is practically insignificant.

Figure 5 shows the influence of the condenser water flow rate on the compressor power consumption for different values of the heating power. In this figure, it can be observed that the increase of water flow rate reduces power consumption of the compressor, which is an interesting result. Its rationale is related to the fact that an increase of the water flow rate yields an increase in the condenser heat transfer rate, in this way, setting the temperature of the superheated vapor leaving the compressor. Therefore, the power consumed by the compressor is directly related to its outlet temperature as well established by thermodynamic principles. However, consistent with the results presented in **Figure 3**, further increase of the water mass flow rate toward the upper end of the tested range leads to no significant reduction of compressor power consumption.

Taking into consideration the results, in particular those reported in **Figures 3** and **5**, respectively, they indicate that increasing values of mass flow rate yield higher values of COP, as it will be shown in **Figure 6**. However, higher values of the water flow rate may lead to outlet temperatures too low for practical usage, which is illustrated by the results presented in **Figure 4**.

Figure 6, as already mentioned, reports the influence of water flow rate on the heat pump COP, it can be noted that the system COP increases with increasing water flow rate. COP experiences a sharp increase from 2.4 to about 3.56 when the water flow rate increases from 0.03 to 0.18 kg/s, respectively, under the heating power of 2400 W. This result is justified on the

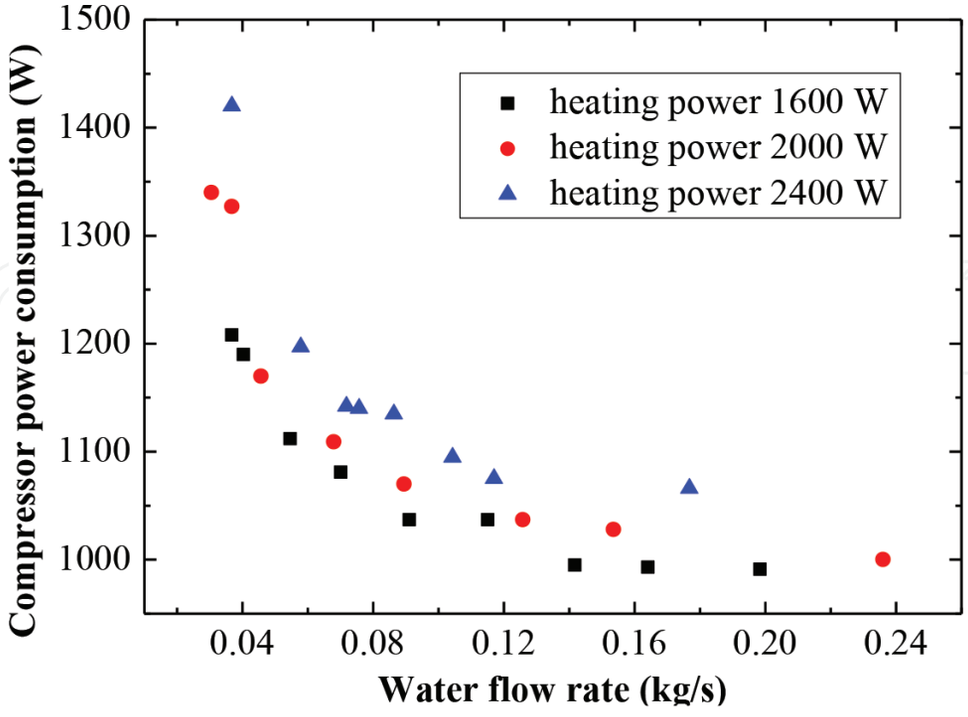


Figure 5. Compressor power consumption as a function of the water flow rate and heating power.

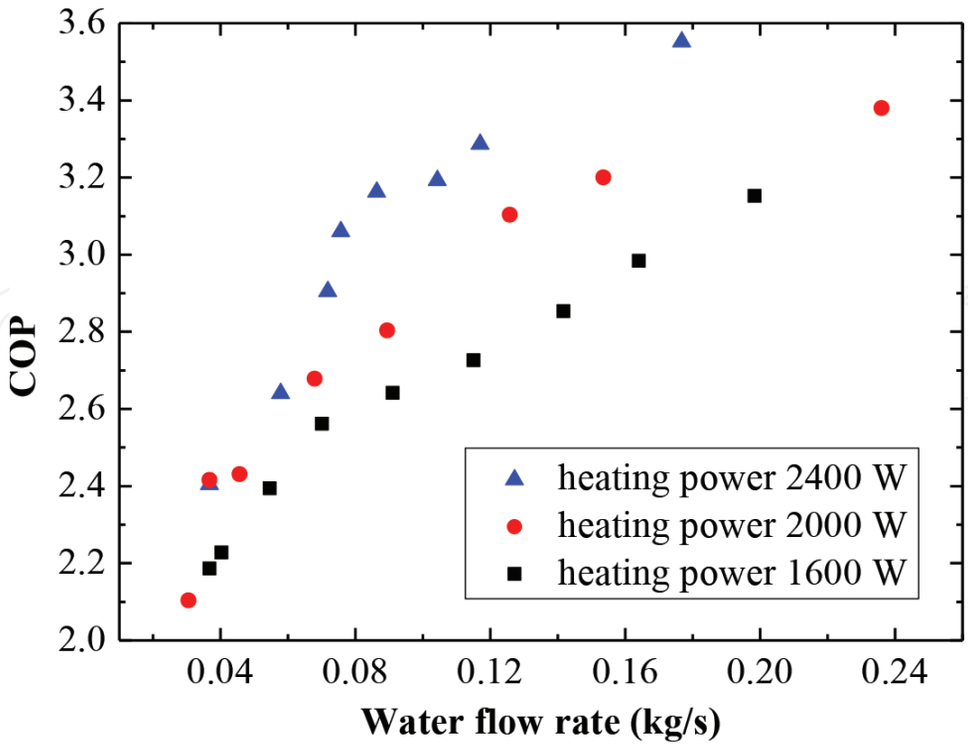


Figure 6. The effect of water flow rate and heating power on the system COP.

basis of data already reported in particular that in **Figures 3** and **5**. In addition, the higher the heating power, the higher the system COP is. It is because that higher heating power will result in higher evaporation temperature and higher evaporation pressure, which reduces the pressure ratio of the compressor and consequently improves the system COP.

The data presented in **Figure 3** are further analyzed in **Figure 7**, and it is clearly shown that the LED leadframe temperature increases with increasing heating power. The experimental results indicate that for a 2400 W heating power level, the LED leadframe temperature can be kept within 60°C. For lower values of LED power, the LED leadframe temperature can even be lower than the surrounding air temperature. Consequently, taking into consideration the correlation between LED lifetime and its junction temperature, the proposed integrated system has the potential of prolonging the lifetime of the LEDs. However, it should be mentioned that in practice, the LED temperature cannot be set lower than that of the dew point of the atmosphere; otherwise, the condensation of the water vapor in the air will damage the electronic components of the LED. Moreover, as already stated, the LEDs should be set at an appropriate temperature, which may lead to an operation close to the maximum energy efficiency of the integrated system.

Also **Figure 8**, further to rearrange data presented in **Figure 5**, indicates that the power absorbed by the compressor increases significantly with increasing LED power; as before, this can be explained on the basis of the increasing flow rate of refrigerant through the compressor, when the heating power increases. The increased mass flow rate, assuming the inlet and outlet states remain the same, will lead to increased power consumption.

http://dx.doi.org/10.5772/intechopen.78322

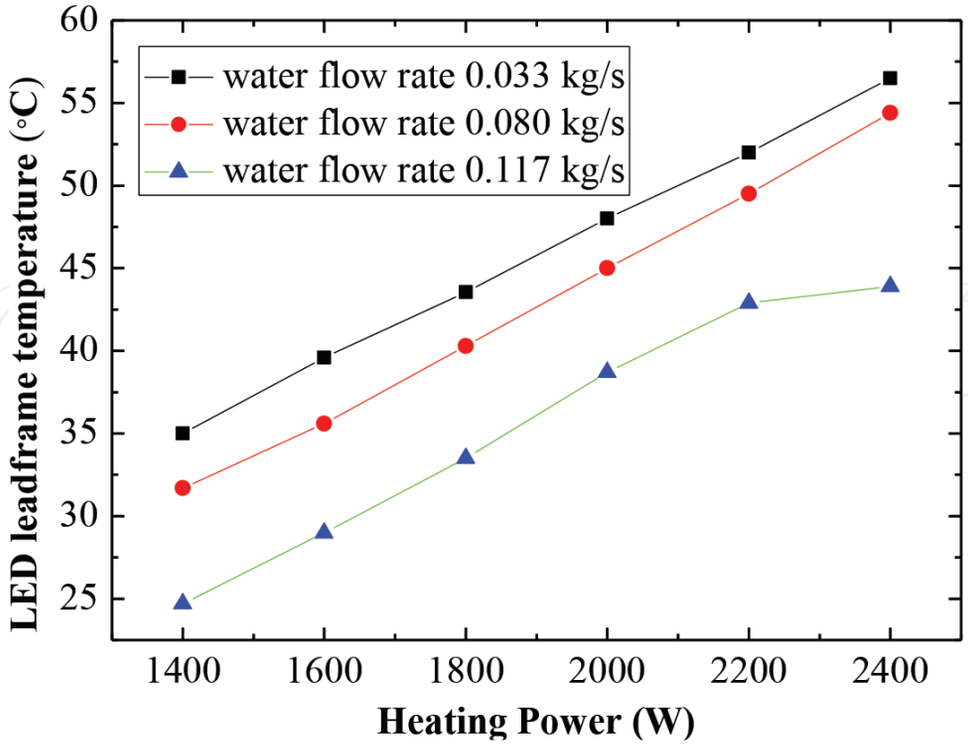


Figure 7. LED leadframe temperature as a function of heating power for different water flow rates.

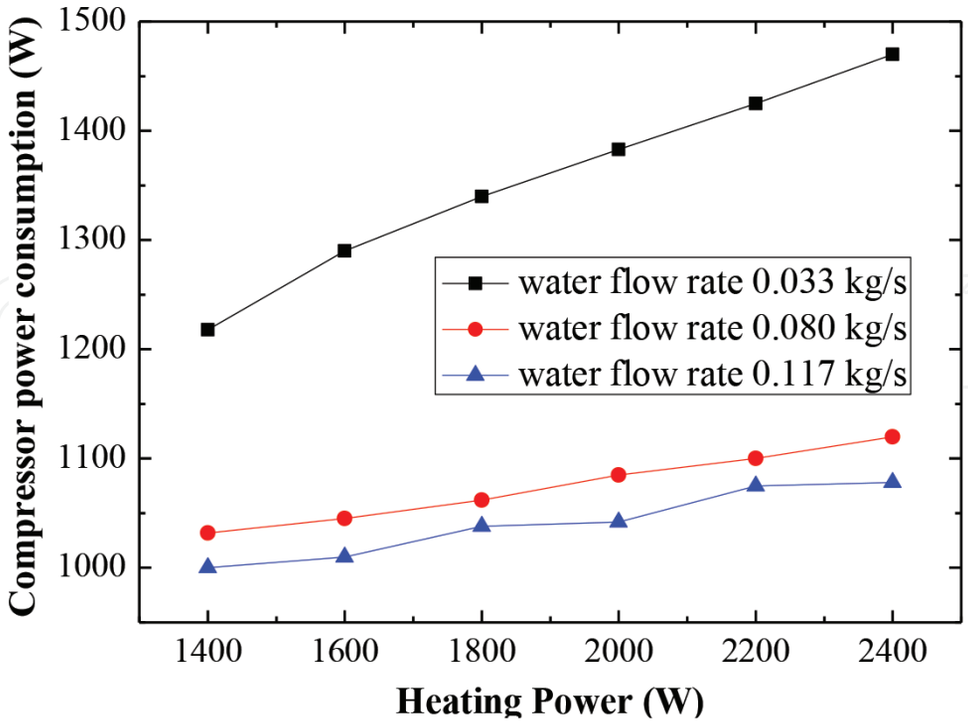


Figure 8. Compressor energy consumption as a function of heating power for different water flow rates.

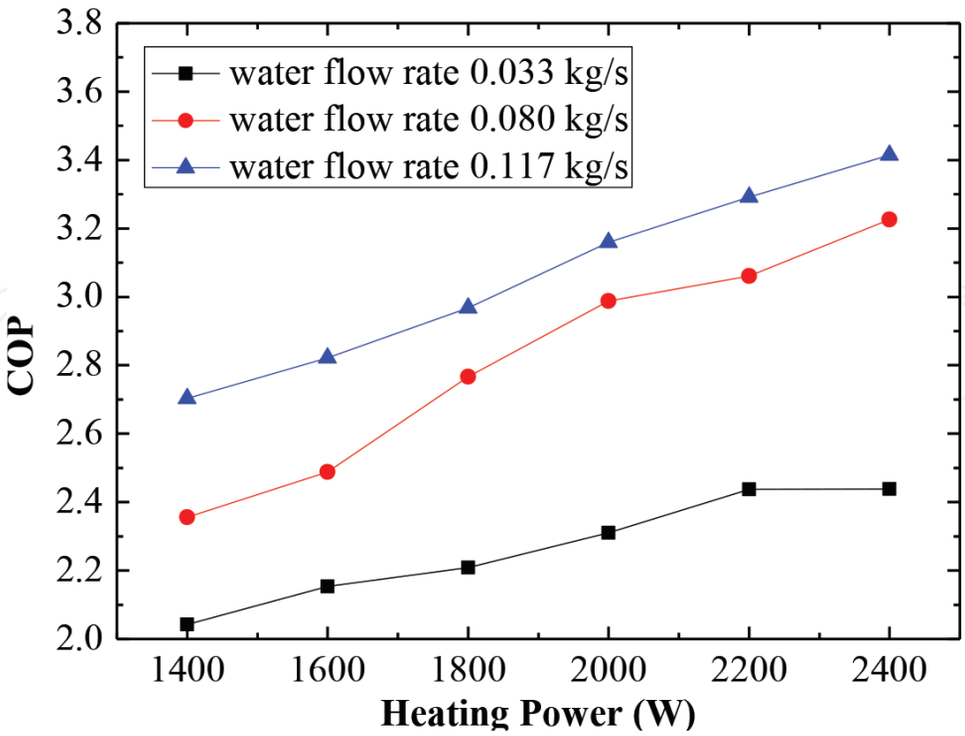


Figure 9. Evolution of system COP with various heating powers.

Figure 9 shows the influence of the total heating power on the system COP. The system COP increases nearly linearly with the total heating power. The increase of the total heating power yields an increase in the evaporating temperature; therefore, the temperature difference between average high temperature T_H side and low temperature T_L side of the heat pump system is reduced. In these conditions considering the COP of the ideal Carnot heat pump cycle, $COP_{ideal} = T_H/(T_H - T_L)$, the heat pump COP of the system should increase. However, in this particular case, the evaporating temperature is limited by the maximum allowed temperature for the LED pn junction.

Table 1 lists the experimental data acquired for the present work when the water inlet temperature is 25.6°C and the total heating power is 2000 W; it encompasses, for different water mass flow rates, the refrigerant inlet and outlet temperatures of evaporator and condenser, respectively, and their refrigerant pressures, water outlet temperature, and compressor power consumption. In addition, the calculated quantities—heat transferred to the water, refrigerant mass flow rate, and specific power consumption of the compressor—are also included in **Table 1**.

As already discussed, for a specific heating power, the water mass flow rate drives the system, as it sets the temperature at the outlet of the compressor (or condenser inlet temperature). Therefore, by increasing the water flow rate, the condenser and evaporator pressures decrease as well as the condenser outlet temperature and the evaporator inlet and outlet temperatures. It is interesting to note that the decrease of the water mass flow rate leads to, although minor, decrease of the refrigerant mass flow rate; consequently, the specific power consumption

$\dot{m}_w \times 10^{-3}$ (kg/s)	T_{e_in} (°C)	T_{e_out} (°C)	T_{c_in} (°C)	T_{c_out} (°C)	$P_e \times 10^6$ (Pa)	$P_c \times 10^6$ (Pa)	T_{w_out} (°C)	W_{comp} (W)	Q_{water} (W)	$\dot{m}_r \times 10^{-3}$ (kg/s)	$SW_{comp} \times 10^3$ (W/(kg/s))
236	−3.1	5.2	39.4	29.1	0.41	1.15	29.01	1000	3379	17.94	55.75
154	−3.0	5.4	40.0	29.2	0.42	1.19	30.7	1028	3289	17.54	58.62
90	−1.6	6.5	40.8	31.5	0.44	1.26	34.08	1070	3187	17.33	61.76
68	−0.2	8.1	42.4	33.7	0.47	1.35	36.5	1109	3113	17.21	64.44
46	2.6	10.1	45.7	37.4	0.51	1.47	40.62	1170	2885	16.32	71.69
31	6.3	13.8	56.1	43.8	0.59	1.75	47.6	1340	2818	16.30	82.22

$\dot{m}_w$: water mass flow rate, T_{e_in}: evaporator inlet temperature, T_{e_out}: evaporator outlet temperature, T_{c_in}: condenser inlet temperature, T_{c_out}: condenser outlet temperature, P_e: evaporator pressure, P_c: condenser pressure, T_{w_out}: water outlet temperature, W_{comp}: compressor power consumption, Q_{water}: condenser heat transfer rate, $\dot{m}_r$: refrigerant mass flow rate, and SW_{comp}: specific power consumption of the compressor.

Table 1. Inlet and outlet temperature of evaporator and condenser and their inside pressures with various water flow rates when total heating power is 2000 W and water inlet temperature is 25.6°C.

experiences a significant increase, which indicates that the difference between the outlet and inlet temperatures of the compressor increases. The heat transfer rate in the condenser, considering that it is an annular heat exchanger, is dominated by the refrigerant side heat transfer coefficient; notwithstanding, the fact that the water side heat transfer coefficient will increase with increasing water mass flow rate.

For the system, as a whole, for a specific heating power generated by the aluminum blocks with inserted cartridge heaters, which mimic LEDs, the increase of the water mass flow rate will have the effect of reducing the temperature in the evaporator (lamp) and consequently the corresponding saturation pressure, resulting in this way an increase in boiling activity yielding an increase in the refrigerant mass flow rate. As expected, the decrease in evaporator pressure tends to be less than that at the condenser. Therefore, by increasing the water mass flow rate, the compressor pressure ratio decreases and, consequently, the COP also increases.

4. The thermodynamic performance limit of the system

According to the first law of thermodynamics and omitting heat leakage from the system to the surroundings, the energy conservation equation of the system can be written as

$$Q_{water} = W_{comp} + (1 - \eta) W_{LED} \tag{5}$$

where η refers to the LED luminous efficiency, and W_{LED} refers to the power consumed by the LED chips.

Theoretically, the heat pump Carnot efficiency is $COP_{ideal} = T_H/(T_H - T_L)$, then considering the definition of the system COP, we have

$$\mathrm{COP} = f\frac{T_H}{(T_H - T_L)} = 1 + \frac{(1-\eta)\mathrm{W_{LED}}}{\mathrm{W}_{comp}} \tag{6}$$

where f is a ratio of the real COP to $\mathrm{COP_{ideal}}$. By increasing the LED power, $\mathrm{T_L}$ will also increase to keep the energy balance. However, the combined increase of refrigerant temperature in the evaporator and LED power results in an even higher LED chip temperature to achieve the required heat transfer between the LED chip and the refrigerant. Irreversibility due to the heat transfer, compression, and throttling processes will keep the values of the heat pump COP much lower than those for the Carnot heat pump. In addition, the increase of the evaporator temperature will result in higher compressor exhausting temperature, which may not satisfy the rated operating condition of the compressor, and its efficiency will deteriorate. In these conditions, Q_{water} will not increase as much as the increase of LED power and the additional heat will be accumulated in the system, in particular in the evaporator. In these circumstances, when the LED power reaches a certain quantity, there is a possibility that the refrigerant liquid phase will be reduced to the point that the LED chip reaches a temperature that will cause burnout.

As shown in **Figure 10**, when the heating power is 2400 W, the LED leadframe temperature can be kept at a stable temperature of 55°C. However, when heating power is increased to 2500 W, the LED leadframe temperature shoots up after a period time of heat accumulation. In the experiment, we also used another compressor with a rated power of 953 W to test its working limit. Its highest allowed heating power was about 1800 W, both compressors have almost the same COP with values higher than 3, when they operate at their highest allowed heating powers.

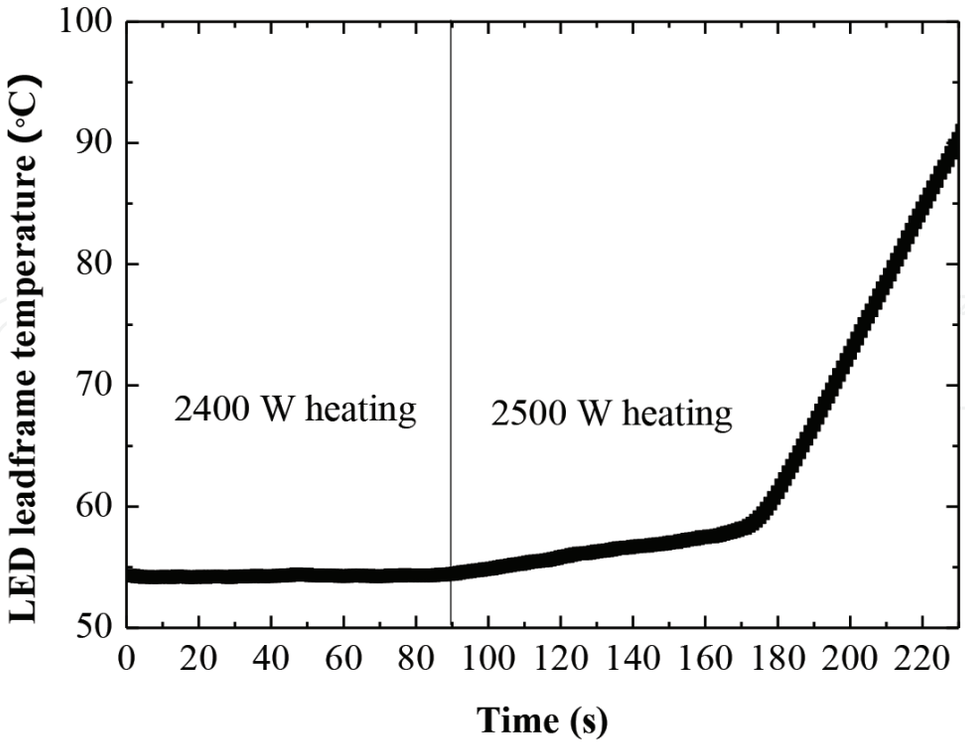


Figure 10. Working limit of the system.

http://dx.doi.org/10.5772/intechopen.78322

5. Conclusions

The present work proposes an integrated system for temperature control and heat recovery to operate in conjunction with an LED lamp. The integrated system consists of a heat pump in which the lamp itself operates as the heat pump evaporator. The temperature control of the LED can be achieved through the coolant (water) flow rate through the condenser. To demonstrate the concept, it was developed as an experimental setup, in which the evaporator mimics a high pole LED lamp. After extensively testing the apparatus, the most significant findings are as follows:

1. Water flow rate has relatively minor influence on the LED leadframe temperature; therefore, when higher temperature water is required, the water flow rate can be reduced without having an escalation of the LED temperature.
2. The increase of water flow rate yields a decrease of the compressor power consumption; however, further increase of the flow does not lead to significant reduction of compressor power consumption.
3. The increase of water flow rate causes the COP to increase, and further increase of the flow only results in minor augmentation of COP.
4. For the highest total heating power tested, i.e., 2400 W, which is equivalent to an LED lamp with a total power of ∼3000 W, the LED leadframe in this experimental setup can be kept at 60°C level; for lower values of LED power, the LED leadframe can even be lower than the surrounding air temperature.
5. LED power increase results in sharp increase of compressor energy consumption.
6. System COP presents a nearly linear relation with LED power.
7. The integrated system working limit occurs when LED power reaches a quantity, which causes the temperature of the compressor to exceed its maximum specified value; under these circumstances, the LED chip may reach burnout conditions.

In conclusion, this integrated system adopts an active method to simultaneously achieve waste heat recovery and LEDs cooling down. For an appropriate compressor rated power, LEDs will be kept within optimal temperature range. In addition, the recovered heat will come in the form of hot water, which may find multiple applications. Moreover, the integrated system avoids dissipating heat to the surroundings, minimizing in this way the environmental impact, and as it does not require a large aluminum finned heat sinks, there is an obvious gain in terms of compactness.

Acknowledgements

This work was supported by Science and Technology Program of Guangzhou, China (grant no. 201604010018), and Science and Technology Program of Guangdong, China (grant no. 2016A010104010). The authors also thank the CAS President's International Fellowship

Initiative Visiting Fellow, Prof. Antonio CM Sousa, for helpful and constructive suggestions when preparing the paper.

Author details

Jiwen Cen[1], Zhibin Li[1], Yiwei Wang[1], Fangming Jiang[1]*, Shaoxiong Liao[2] and Fuwen Liang[2]

*Address all correspondence to: fm_jiang2000@yahoo.com

1 Laboratory of Advanced Energy Systems, CAS Key Laboratory of Renewable Energy, Guangdong Key Laboratory of New and Renewable Energy Research and Development, Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences (CAS), China

2 Tiger Fire (Guangzhou) Technology Co., Ltd., Guangzhou, China

References

[1] Almeida AD, Santos B, Paolo B, Quicheron M. Solid state lighting review-potential and challenges in Europe. Renewable and Sustainable Energy Reviews. 2014;**34**:30-48

[2] Park DH, Lee DB, Seo ER, Park YJ. A parametric study on heat dissipation from a LED-lamp. Applied Thermal Engineering. 2016;**108**:1261-1267

[3] Tang Y, Ding X, Yu B, Li Z, Liu B. A high power LED device with chips directly mounted on heat pipes. Applied Thermal Engineering. 2014;**66**:632-639

[4] Deng Y, Liu J. A liquid metal cooling system for the thermal management of high power LEDs. International Communications in Heat and Mass Transfer. 2010;**37**:788-791

[5] Lin Z, Wang S, Huo J, Hu Y, Chen J, Zhang W, Lee E. Heat transfer characteristics and LED heat sink application of aluminum plate oscillating heat pipes. Applied Thermal Engineering. 2011;**31**:2221-2229

[6] Shin DH, Baek SH, Ko HS. Development of heat sink with ionic wind for LED cooling. International Journal of Heat and Mass Transfer. 2016;**93**:516-528

[7] Wang J, Cai Y-X, Bao W-W, Li H-X, Liu Q. Experimental study of high power LEDs heat dissipation based on corona discharge. Applied Thermal Engineering. 2016;**98**:420-429

[8] Yung KC, Liem H, Choy HS. Heat transfer analysis of a high-brightness LED array on PCB under different placement configurations. International Communications in Heat and Mass Transfer. 2014;**53**:79-86

[9] Park S-J, Jang D, Yook S-J, Lee K-S. Optimization of a chimney design for cooling efficiency of a radial heat sink in a LED downlight. Energy Conversion and Management. 2016;**114**:180-187

[10] Park S-J, Jang D, Lee K-S. Thermal performance and orientation effect of an inclined cross-cut cylindrical heat sink for LED light bulbs. International Journal of Heat and Mass Transfer. 2016;**103**:1371-1377

[11] Xiao C, Liao H, Wang Y, Li J, Zhu W. A novel automated heat-pipe cooling device for high-power LEDs. Applied Thermal Engineering. 2017;**111**:1320-1329

[12] Sömen KF, Yürüklü E, Yamankaradeniz N. Computational thermal analysis of cylindrical fin design parameters and a new methodology for defining fin structure in LED automobile headlamp cooling applications. Applied Thermal Engineering. 2016;**94**:534-542

[13] Jeng T-M, Tzeng S-C, Lin Y-C. Experimental study of heat transfer enhancement of inserted LED lamp by the closed-cell aluminum-foam ceiling. International Communications in Heat and Mass Transfer. 2015;**66**:233-239

[14] Wu Y, Tang Y, Li Z, Ding X, Yuan W, Zhao X, Binhai Y. Experimental investigation of a PCM-HP heat sink on its thermal performance and anti-thermal-shock capacity for high-power LEDs. Applied Thermal Engineering. 2016;**108**:192-203

[15] Sufian SF, Abdullah MZ. Heat transfer enhancement of LEDs with a combination of piezoelectric fans and a heat sink. Microelectronics Reliability. 2017;**68**:39-50

[16] Zhao X-J, Cai Y-X, Wang J, Li X-H, Zhang C. Thermal model design and analysis of the high-power LED automotive headlight cooling device. Applied Thermal Engineering. 2015;**75**:248-258

[17] Kang X, Wang Y, Huang Q, Cui Y, Wang C, Wen C, Fan J. Phase-change immersion cooling high power light emitting diodes and heat transfer improvement. Microelectronics Reliability. 2017;**79**:257-264

[18] Ahn B-L, Yoo S, Kim J, Jeong H, Leigh S-B, Jang C-Y. Thermal management of LED lighting integrated with HVAC systems in office buildings. Energy and Buildings. 2016; **127**:1159-1170

[19] Ahn B-L, Jang C-Y, Leigh S-B, Yoo S, Jeong H. Effect of LED lighting on the cooling and heating loads in office buildings. Applied Energy. 2014;**113**:1484-1489

IntechOpen

IntechOpen