In plant factories, LED lighting fixtures significantly contribute to energy consumption around 40 to 50% [Montes Rivera, Martín, Nivia Escalante-García, José Alonso Dena-Aguilar, Ernesto Olvera-Gonzalez and Paulino Vacas-Jacques. “Feature Selection to Predict LED Light Energy Consumption with Specific Light Recipes in Closed Plant Production Systems.” *Applied Sciences* (2022): n. pag. doi: 10.3390/app12125901] , it also serve as a primary source of heat (80%) that directly impacts the cooling load on air conditioning systems [Hai, Bin, Yu., Haiye, Yu., Bo, Zhang., Yuanyuan, Sui. (2023). Quantitative Perturbation Analysis of Plant Factory LED Heat Dissipation on Crop Microclimate. Horticulturae, doi: 10.3390/horticulturae9060660]. Efficient removal of heat generated by LEDs not only alleviates the cooling load on air conditioning systems, thereby reducing overall energy consumpt, but also holds promise for enhancing the luminous efficacy of the LEDs themselves. Actually it is a common knowledge the luminous efficacy of LEDs decreases with increasing temperature in junction and thermal resistance of LEDs. [Quispe, M R, F Oscco, Martin John Horn and M M Gómez. “Influence of the temperature of a white LED on its lighting characteristics.” *Journal of Physics: Conference Series* 2538 (2023): n. pag. doi: 10.1088/1742-6596/2538/1/012009] [Peng, Dongsheng and K L Liu. “Effect of ambient temperature and heating time on high-power LED.” *Journal of Physics: Conference Series* 1777 (2021): n. pag. doi: 10.1088/1742-6596/1777/1/012033] [Markowicz, Marek, Emil Smyk and Robert Smusz. “Experimental study of the LED lamp.” *MATEC Web of Conferences* (2021): n. pag. doi:10.1051/MATECCONF/202133801015] . Furthermore, Yuan et al. proved after about 800 hours of working, the luminous efficiency of the LEDs decreased significantly, meaning the duration of operation time of LEDs is also crucial for its luminous efficiency. [Fei Yuan, Kailin Pan, Yu Guo and Shujing Chen, “Study on thermal degradation of high power LEDs during high temperature and electrical aging,”  2013 10th China International Forum on Solid State Lighting (ChinaSSL)\_, Beijing, 2013, pp. 150-153, doi: 10.1109/SSLCHINA.2013.7177336.]

By discussing the heat losses in phosphor-converted LEDs, researchers like Lisitsyn et al. emphasizes that reducing energy losses caused by heating is crucial for enhancing the luminous efficacy of LEDs. [Lisitsyn, Viktor M., V. S. Lukash, Sergey Stepanov and Ju Yangyang. “White LEDs with limit luminous efficacy.” (2016). doi: 10.1063/1.4937863] .

所以led灯散热量的有效处理不仅事关冷负荷也就是能耗，也跟led自身芯片可持续运行息息相关。

Presently, cooling technologies for LED components mainly encompass air cooling, liquid cooling, and immersion cooling methods [Matthew, T., Siedhoff. (2022). Immersion Cooling of Suspended and Coated Nano-Phosphor Particles for Extending the Limits of Optical Extraction of Light Emitting Diodes. Journal of Heat Transfer-transactions of The Asme, doi: 10.1115/1.4055568]

Air cooling techniques include the use of air to blow accross a heat sink connected to the heat source in order to take the heat away through convective heat transfer. Air cooling techniques have reached a notable level of maturity in electronics cooling applications, especially for electronics that has power rate below 300 W [@kheirabadiCoolingServerElectronics2016]; With LED being also an electronic device, direct application of air-cooling heatsinks can address the heating issue associated with LEDs; however, the heat dissipated from LEDs still permeates into indoor air, affecting temperature and humidity control inside the plant factory, rendering it an incomplete solution to the problem at hand. It has also been noted that due to poor thermophysical properties, air cooling requires high flow rate and low coolant temperature compared to other liquid cooling strategies.[@kheirabadiCoolingServerElectronics2016]

Indirect liquid cooling involves heat dissipation in a manner such that no direct contact exists between the liquid coolant and electronic components. This strategy is implemented by replacing traditional air cooled heat sinks with some form of liquid cooled heat sink or evaporator. [H. Geng, Data Center Handbook, John Wiley & Sons, Inc., New Jersey, 2015.]

Other than that, Y. Lai et al proved with experiments that active liquid cooling is an effective solution for high brightness LEDs in automotive headlights, outperforming air cooling and passive liquid cooling methods. [@lai2009].

— start-multi-column: Hsieh et al. microspray

number of columns: 2   
largest column: left

Hsieh et al. proposed a microspray-based cooling system for LEDs, realizing temperature drop up to 40 degrees for single LED that output 3W and 5 W of powers. [@hsieh2014]

— end-column —

![[microspray\_litrvw.jpg]]

— end-multi-column Deng et al presented an active liquid cooling solution that replace water to liquid metal, it is due to its high density (up to 7 times higher) and strong thermal conductivity (more than 20 times higher) compared to water, allowing it to dissipate heat more easily than water even though its heat capacity is around 10 times smaller than water. [@dengLiquidMetalCooling2010]

There numerous possible configurations when it comes to cooling LEDs. However, when implemented in plant factories, challenges such as transferring heat across multiple layers of growing racks and ensuring effective outdoor heat expulsion are ought to be overcomed.

Based on the above discussion, this paper proposes a novel cooling solution aiming to:

* Design and implement an efficient heat conduction mechanism for LED aluminum substrates, rapidly removing the generated heat.
* Transfer this heat to a sustainable heat storage pool designed for directional discharge to the outdoor environment.

The ultimate objectives envisioned are:

* Achieving zero-energy cooling of LED chips during cooling operations;
* Recouping and reusing waste heat generated by LEDs without compromising their light output performance under heating conditions.