

Characteristics of Frost Growth On Micro-Channel Heat Exchangers

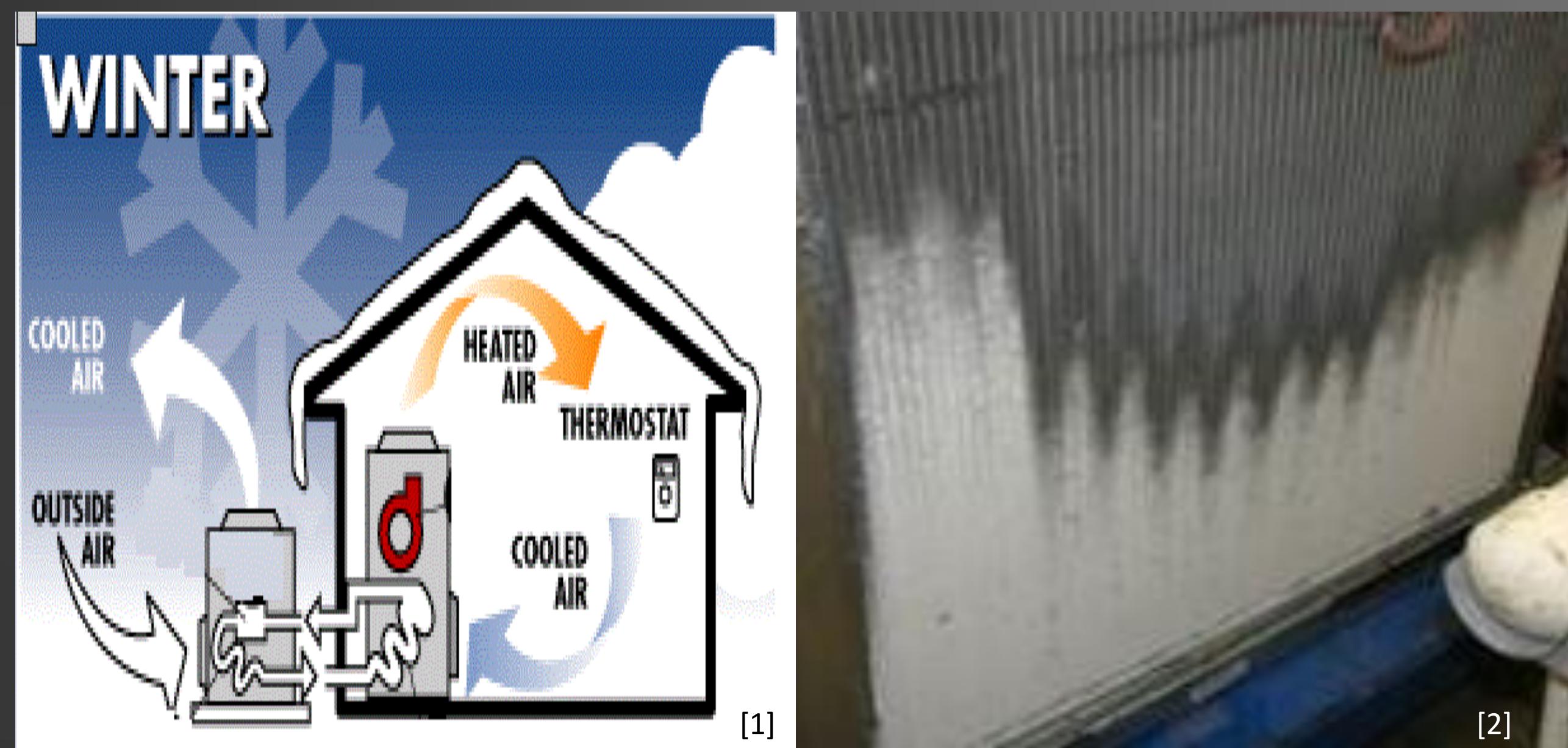


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Introduction

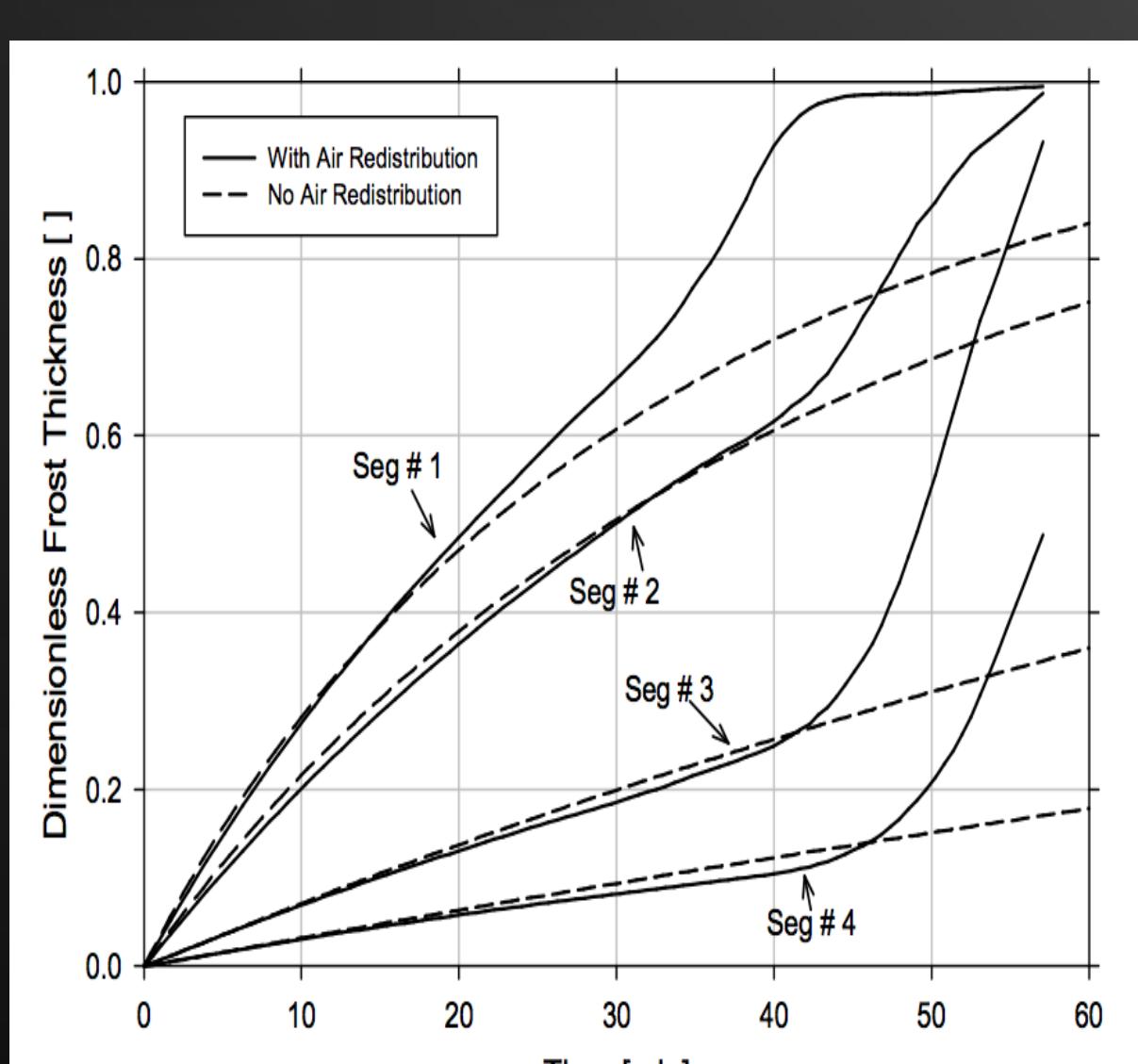
Micro-channel heat exchangers are essential components of air-to-air heat pumps, also referred to as air source heat pumps. Air source heat pumps are installed on houses and buildings as an energy efficient alternative to provide heat in the winter and also act as an air conditioner in the summer. A major issue that arises when the heat pump is exposed to winter conditions. As the cold, humid air flows through the heat exchanger, it causes frost to buildup on the fins, greatly reducing the effectiveness of the heat pump. Currently, heat pumps are programmed to run periodic defrost cycles in the winter, but this is highly inefficient. Micro-channel heat exchangers transfer energy much better than fin-tube heat exchangers; however, they frost considerably faster due to the increased surface area and decreased fin spacing, thus preventing them from being used on heat pumps. The frosting of heat exchangers is also a problem for the heat pump manufacturers to describe the energy performance of the air source heat pump during frosting conditions. Preventing frost growth on micro-channel heat exchangers would greatly enhance the performance of air source heat pumps and also save large amounts of energy.



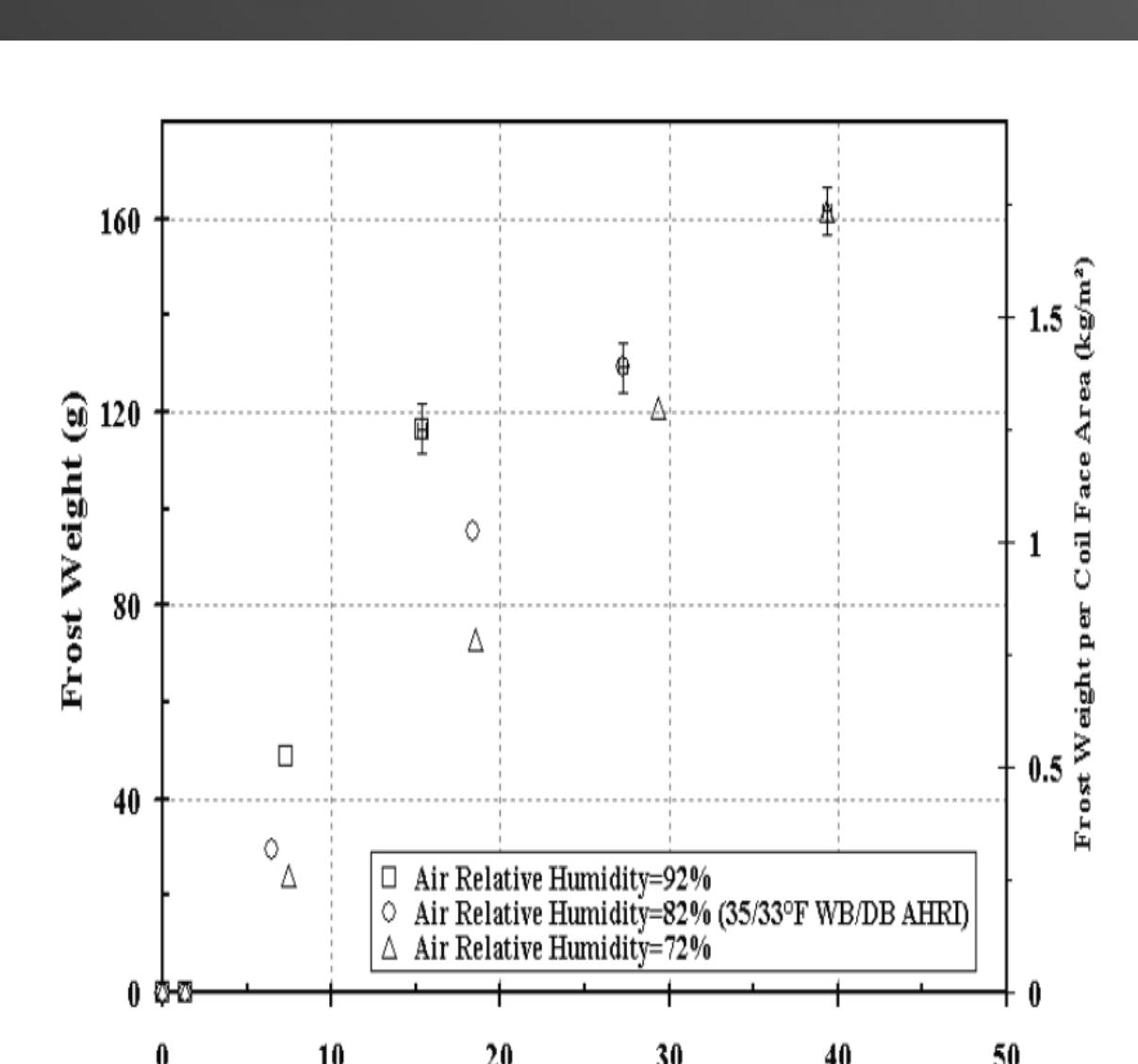
Frost Growth Models

There have been several mathematical frost growth models developed, but due to the complexity of the system, none of them have the accuracy that is desired. Many of the models are lacking important details. For example, Yang et al [3] developed a mathematical model to predict frost growth on fin-tube heat exchangers; however, fin temperature was held constant in the model. In reality, characteristics of the frost cause fin temperature to fluctuate. Understanding frost growth characteristics, specifically mass and density, would allow us to account for variables that depend on these characteristics. We are working closely with the engineering department at Oklahoma State University in an attempt to develop an accurate model for frost growth on micro-channel heat exchangers.

Frost Thickness at Various Segments of the Heat Exchanger



Overall Frost Weight on the Heat Exchanger



$$\Delta P = \frac{G_a}{2\rho_{in}} \left[(K_i + 1 - \sigma^2) + 2 \left(\frac{\rho_{in}}{\rho_{out}} - 1 \right) + f \left(\frac{A_o}{A_m} \right) \left(\frac{\rho_{in}}{\rho_{out}} \right) - \left(1 - \sigma^2 - K_e \right) \frac{\rho_{in}}{\rho_{out}} \right] \quad [5]$$

Mass of Water vapor that diffuses into the frost layer

$$\dot{m}_{f,\delta} = h_m A_s (\rho_\infty - \rho_{f\delta}) - \dot{m}_{f,\rho} \quad [6]$$

$$\rho_f = \frac{\int_0^t h_m \Delta \rho_v dt}{\delta_f} \quad [7]$$

Average Frost Density

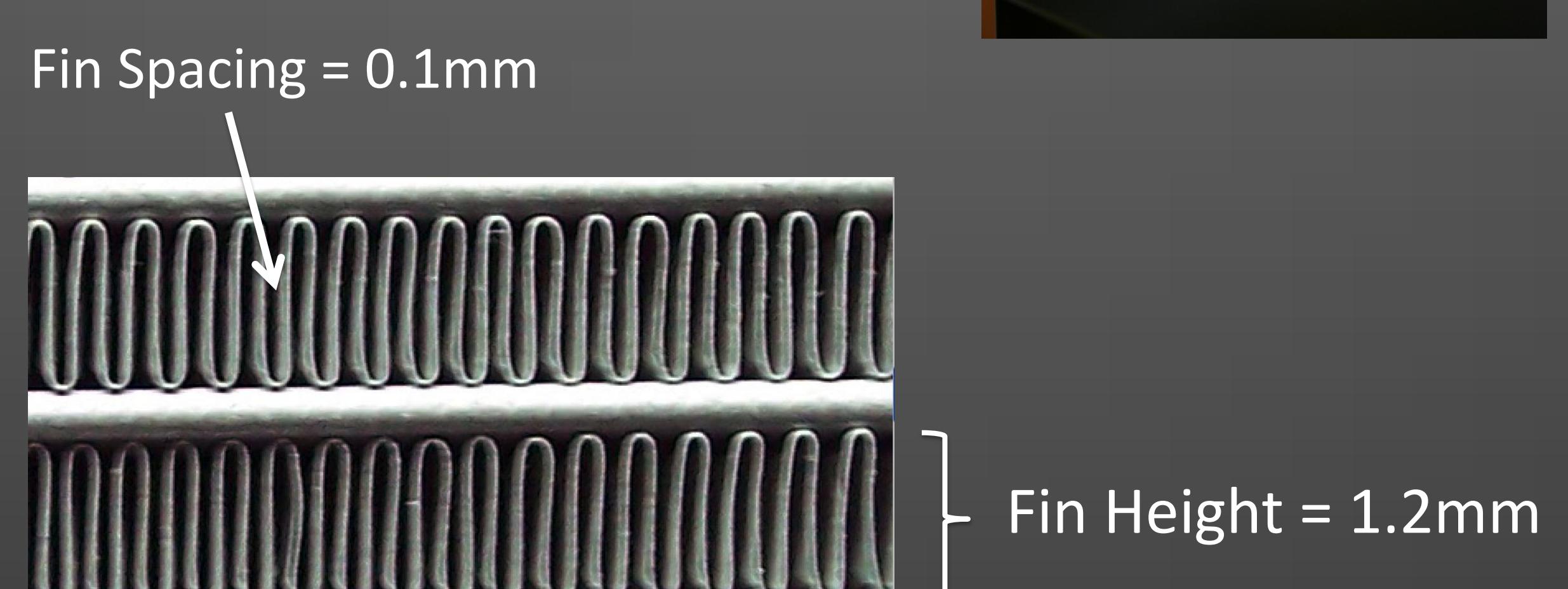
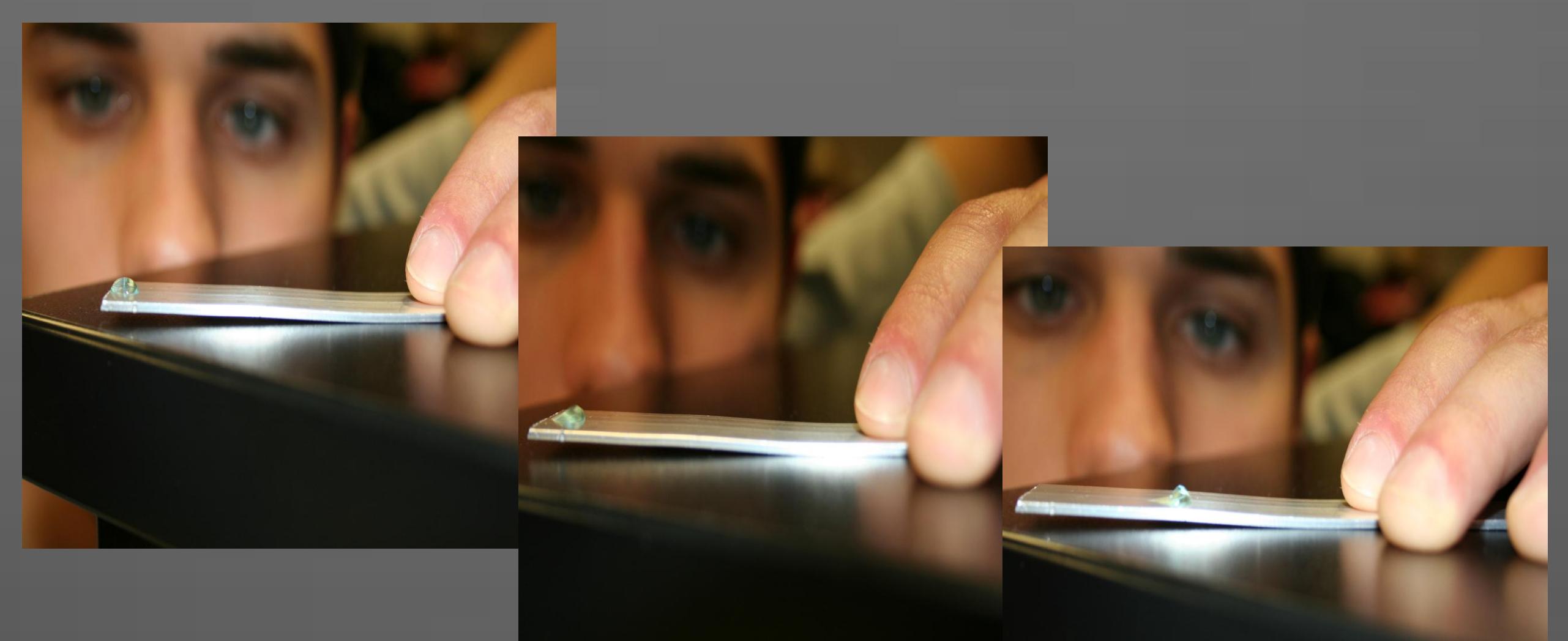
$$\rho_f = 670 e^{0.277 T_{fs}} \quad [8]$$

Notice the re-occurrence of density in the equations

Symbol	Quantity	SI Unit	
A	Surface area	m^2	
f	Coil friction factor	-	
h	Heat transfer coefficient	W/m K	
G	Mass flux	$\text{kg/m}^2 \text{s}$	
h_m	Mass transfer coefficient	m/s	
k	Heat of sublimation	J/kg	
K_i, K_e	Conductivity	W/m K	
$K_{in, K_{out}}$	Inlet and Exit coefficient for coil pressure drop calculations	-	
\dot{m}	Mass flow rate	kg/s	
P	Pressure	Pa	
T	Temperature	$^\circ\text{C}$	
δ	Thickness	m	
ρ	Density	kg/m^3	
σ	Ratio of minimum free flow area to frontal area		

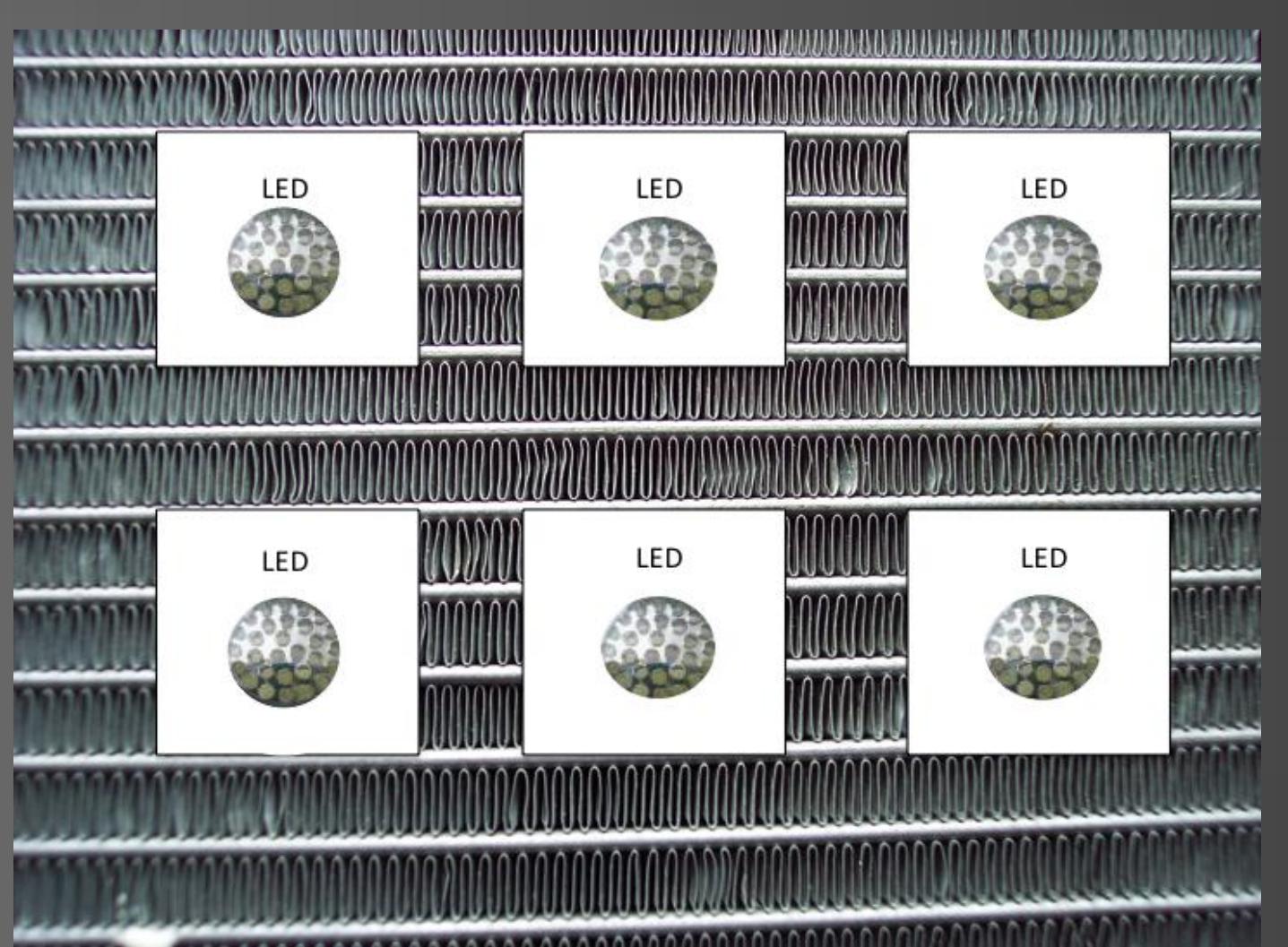
Objective

The overall goal is to prevent frost from forming on the micro-channel heat exchanger. To accomplish this, we first need the means to analyze unknown characteristics of frost formation on the heat exchanger. Frost density plays a significant role in the frost models. Fin temperature, airflow rates, and refrigerant temperature are just a few of the variables that are dependent on frost distribution and frost density. The frost growth is not uniform throughout the heat exchanger [9]; therefore it would be beneficial to have the ability to calculate the mass distribution of the frost across the heat exchanger and also be able to compare the densities of frost according to specific regions on the heat exchanger. Calculating the mass and comparing densities of the frost at various locations of the heat exchanger would enable us to present a much more accurate frost growth model. We have developed a design and a method to physically measure the mass distribution of frost across the heat exchanger and also compare the densities of the frost according to different regions of the heat exchanger.



Design and Method

We have designed a template that splits the heat exchanger into six different regions. Each region contains an LED light. The light rays are channeled to the according region and the light intensity is measured on the other side of the heat exchanger. The region that yields the lowest light intensity represents region that contains the densest frost. The least dense frost region will yield the highest light intensity. We have also developed a method to physically measure the mass of the frost. Kondepudi and O'Neal [10] attempted to calculate the mass of the frost by melting the frost off of the heat exchanger and then measuring the mass of the water, but they were not able to get a large portion of the water droplets off of the heat exchanger. This is due to the polarity of the water. Our method consists of blowing a combination of fluorocarbon gases to force the water droplets off of the heat exchanger. The fluorocarbons are non-polar; therefore, they do not stick to the water droplets. We engineered a template, much similar to the one used with the LED lights, that attaches to the heat exchanger to "catch" the water droplets from each region. Then, we can weigh water, resulting in the mass of the frost.



Conclusion

We believe that our design and method will allow us to measure the mass of the water and compare the densities of specific regions on the heat exchanger. We plan to further our research by gathering data while frosting a micro-channel heat exchanger in the wind tunnel at Oklahoma State University. The wind tunnel provides a real life environment and also allows us to control the environment. We will have the ability to measure many of the variables involved with understanding frost growth, such as fin temperature, airflow rates, refrigerant temperature, and air temperature. This will enable us to improve current frost growth models and better understand frost formation on the heat exchanger, potentially leading to preventing frost growth on the heat exchanger.

Acknowledgements

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