BIPV/T Airflow Analysis for Ideal Heat Transfer

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Abstract

An air-channel model was developed to conduct simulations for heat transfer and airflow improvements by introducing flow disruptors into an integrated photovoltaic thermal (BIPV/T) collector. A simulation model was developed for the air channel that would extract excess heat from the panels. The model specifically focused on the development of increasing efficiency by improvement of heat transfer within the BIPV/T system to manipulate air into becoming turbulent, which will increase its thermal capacity and heat transfer capabilities. Paired with an air source heat pump (ASHP), the BIPV/T's pre-heated air serves to increase the coefficient of performance of the AHSP while increasing the photovoltaic (PV) panel efficiency. The models were used to predict thermal performance and behavior of the air within the channel as it moved through the system. Different configurations and enhancement concepts were simulated and analyzed to determine the most effective. The final iteration involves the use of a metal mesh to assist in the creation of turbulent flow and with heat transfer to the fluid.

Introduction

Natural gas furnaces dominate the air heating market due to the lower cost of natural gas in Ontario. In residential heating systems, this comes at an additional cost to the home owner through electricity or gas consumption. The cost to heat up a home is steadily increasing as the cost of energy increases. Owing to increasing climate regulations, there is a goal to lower carbon footprints in Canada through carbon tax to help with carbon emissions. This means that gas companies will pass the cost of the new tax to the consumer, which will in turn, increase the cost of natural gas. Electrical companies utilizing natural gas consumption will increase costs to supplement the new energy prices, thus, the cost of heating a home in Canada will increase on a yearly basis to react to the new costs set by the government. The most effective method of residential energy generation is by use of solar panels which take up far less space than other conventional systems and make use of a free energy source. The main objective is to design a system to increase the heat exchange between the supplied outdoor fresh air and the solar panel radiation. A simple and cost-effective way to increase heat transfer and thermal performance of the BIPV/T system was necessary. The design will be reviewed for increases in efficiency and will be analyzed to compare theoretical outputs when altering parameters and configurations.

By using simple cost-effective methods, future developments and implementations can lead to an enticing replacement of roofing systems that provide customers a free source of energy to be used. The development of BIPV/T system allows for the cogeneration of electrical and thermal energy that can be used to further reduce a building's energy consumption. Thus, saving customers money in a more economical and carbon-free way. The BIPV/T can provide shelter, electricity, and heat from a single roofing system.

Background

As of now, typical commercially available photovoltaic (PV) systems are not efficient at turning solar radiation into electrical energy - PV modules commonly have efficiency levels of 6-18% [1]. Remainder of the energy is lost as reflection or as heat. On each roof panel, there is a sealed channel for air movement underneath the PV cells. This thermal duct system warms the air to supplement air heating in the homes. he air travelling through this channel extracts some of the wasted heat that would otherwise be transferred to the atmospheric surroundings. As the air heats up, it can be pumped into the house for heating use and can also be pumped back out of the house. The development of prototype BIPV/T systems continue in order to lower system costs for labour and materials and to make them cost competitive with current PV systems so that they may be implemented in the near future.

Experimental Study

The purpose of the simulations and data acquisition were done to identify flow patterns of air in the channel given certain design conditions as well as the associated heat transfer effectiveness. Aim to achieve turbulence and high Reynold's number with the already designed BIPV/T system, being tested at the Kortright Center, will be considered for the bench mark. The simulation for this system is shown below in *Figure 1*. Note that the inlet is positioned on the bottom of the system as shown in the simulation.

Figure 1: Benchmark - No enhancements

Three concepts were simulated to compare and select the initial design and are shown below in *Figure 2, Figure 3,* and *Figure 4*. Each concept altered the positioning of the fan inlet from the bottom of the system (shown as top row of image) to the side of the system (shown as bottom row of image).

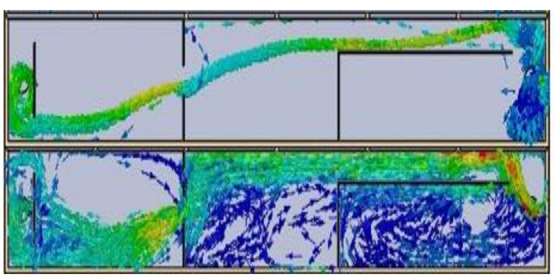

Figure 2: Concept 1 - Guiding walls enhancement

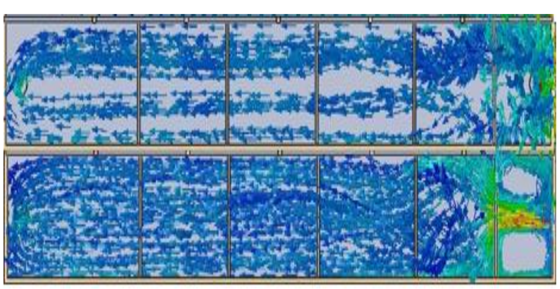

Figure 3: Concept 2 - Fins enhancement

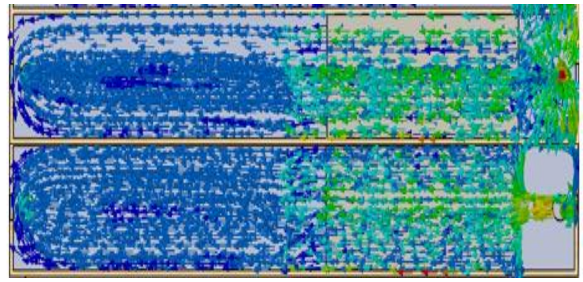

Figure 4: Concept 3 - Foam/mesh enhancement

Concept 3 was selected as initial design due to its ability to distribute the air evenly and promote mixing inside the channel significantly better than the other concept designs 1 and 2.
Across the duct system's assembly, the Reynold's number, airflow velocity, and temperature for the initial design is shown below in **Table 1**.

Table 1: Reynold's number, velocity, and temperature across initial concept system

x (m)	Re	V (m/s)	T (*C)
0.63	35097.29	2.02	1.34
1.36	32240.54	1.84	2.33
2.42	33668.92	2.36	4.37
3.38	45912.16	2.73	6.01
4.49	44279.73	4.68	8.47
6.52	33566.89	1.91	8.68

It can be observed that the initial design met the requirement of increasing temperature from inlet to outlet while maintaining a turbulent state throughout. This suggested that this system was adequate for the design, however, improvements could be made.

After analyzing the concept design along with the initial design, the best aspects of each were merged to create a final he best aspects of each concept design. The final system design made use of a fin baffle coupled with a porous metal mesh arrangement throughout the duct system. The final design simulation is shown in *Figure 5* below:

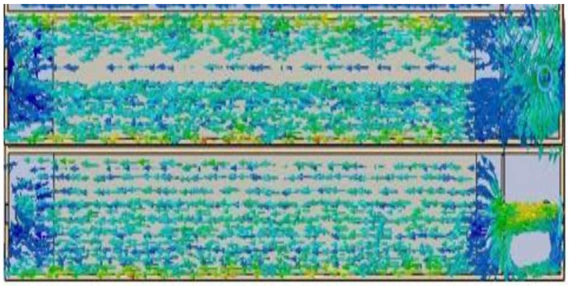

Figure 5: Final Design Simulation

Again, across the duct system's assembly, the Reynold's number, airflow velocity, and temperature for the final design is shown in **Table 2.**

Table 2: Reynold's number, velocity, and temperature across final concept system

x (m)	Re	V (m/s)	T (*C)
0.63	54278.37	2.66	1.67
1.36	37545.94	1.84	2.30
2.42	47748.65	2.34	4.31
3.38	55298.64	2.71	5.93
4.49	95497.29	4.68	8.44
6.52	38974.32	1.91	8.66

Can observe that while velocity remained consistent in both initial and final systems, the final design generates significantly higher Reynold's number throughout the assembly. On average, the final design has a slightly higher increase in temperature. Although it may not seem relevant, for every degree above designed operational conditions, the efficiency of solar panels will reduce by an average of 0.4 % [2] - this is dependent on how the solar panel is manufactured. Reducing as much heat from the panel surface as possible is a priority.

Conclusion & Recommendations

Three concepts were created to be analyzed and the most favorable features of each concept was merged into the final design. It was determined that the best initial concept utilized a fin baffle with a porous metal mesh system. The goal of increasing temperature due to natural heat transfer of waste solar heat was accomplished. Using 150 W/m^2K of thermal transmittance, we were able to increase the temperature of the air from 0°C to approximately 8.66°C. It was concluded that creating high amounts of turbulence resulted in more heat transfer to the air and thus a higher temperature increase. The Reynold's number of a system has a larger impact on the temperature change and therefore must be highly considered when producing BIPV/T systems for commercial use on residential buildings.

Some recommendations to further enhance the BIPV/T system would be to obtain funding to implement control and sensors for the data desired as early as possible to give time for calibration and data collection as well as to allow for observation and more detailed analysis. This primarily includes resistance temperature detectors, pressure sensors, and flowmeters. Further investigation may include; considering the number and positioning of enhancement apparatus that will provide the most absorption of heat from the solar panel and allow maximum extraction of that heat into the air as well as materials used in the apparatus and their characteristics. Different materials and characteristics, or combinations thereof, will have physical properties that will enhance thermal performance and ensure components will continue to function at acceptable levels during operations. These recommendations will help increase the change of temperature along the thermal duct, thus, extracting more waste heat and putting it to use.

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