The Design of a Split Loop Thermosyphon Heat Exchanger for Use in HVAC Applications

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Abstract

While the heat pipe is traditionally considered for thermal management of electronics and relatively small scale systems, heat pipes should also be considered in larger commercial/industrial applications. One area in particular is in Heating, Ventilation, and Air Conditioning (HVAC) systems. Heat pipe heat exchangers can be used to realize significant energy savings where large volumes of ventilation air are required to achieve indoor air quality standards. In this paper, the authors describe an innovative, passive, split loop thermosyphon air-to-air heat exchanger. Design methodology and trade-offs will be explored and the final design performance will be compared to alternative solutions. Also included in the paper is a case study demonstrating the practical use of the technology at a hospital in Seoul, South Korea.

Keywords: Energy recovery; HVAC; Split loop thermosyphon; Air-to-air heat exchanger

1. INTRODUCTION

Maintaining a high level of indoor air quality requires a significant amount of ventilation air. Stale indoor air must be frequently exchanged with fresh outside air. This outside air that is brought into the building must be heated in the winter and cooled in the summer by the active HVAC system to maintain the indoor air temperature at about 22°C. The heating and cooling of the outside air requires a tremendous amount of energy for a large building like a hospital. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 62.1 defines the required levels of ventilation (number of room air volume exchanges per hour) for acceptable indoor air quality. ASHRAE standards also drive local building codes.

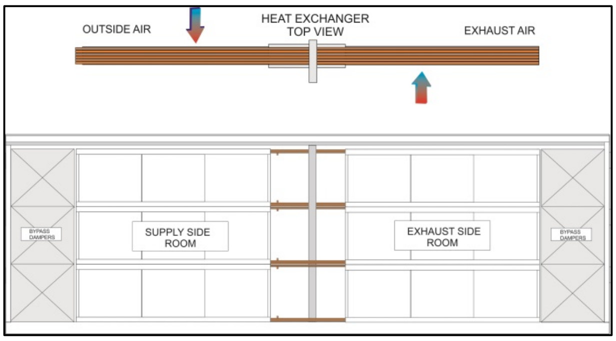

Fig. 1. Top/Front View of a large (1.2m tall x 2.9m wide) Split Loop Thermosyphon Heat Exchanger

At the same time as outdoor air is being drawn into the building, an equal amount of indoor air that has been previously conditioned to 22°C is being discharged from the building. These two air streams pass through ACT's split loop thermosyphon air-to-air heat exchanger, shown in Figure 1. In the winter, the heat from the warm discharge air is transferred passively by the heat pipe heat exchanger to the incoming outside air. Therefore, the demand on the active heating system is significantly less.

The difference between a standard air to air heat pipe heat exchanger and a split loop thermosyphon is found in the circuiting between the warm and cool side heat exchanger coils. A standard air-to-air heat pipe heat exchanger has many individual heat pipes that run the entire length of the heat exchanger, with the evaporator portion of the heat pipe extending into the warm air duct and the condenser end of the heat pipe terminating in the cool air duct. Each heat pipe functions similarly to traditional heat pipe theory with the vapor flowing down the center of the pipe while the liquid returns along the wall.

Alternatively, a split loop thermosyphon is divided into a fewer number of circuits, typically one circuit per row of tubes in the heat exchanger coil. Each row is a dedicated circuit which shares a common liquid and vapor header which allows the liquid and vapor to flow in the same direction. This type of design does not reach the limits (entrainment, flooding) of the traditional counter-flow heat pipe; and therefore, the split loop thermosyphon is able to transfer more heat per unit volume than the standard, heat pipe air-to-air heat exchanger. Another benefit is that because the system contains only two connecting tubes per circuit, retrofit into many applications with minimal changes to existing ductwork or separation walls is possible.

2. DESIGN

The type of air-to-air heat exchanger discussed here consists primarily of linked finned-tube heat exchangers, as shown in Fig. 2. Each finned-tube may be connected individually or through a manifold. The tubes are then filled in a way to ensure the working fluid is at saturation with vapor and liquid existing at equilibrium. During operation, one finned-tube heat exchanger is exposed to a relatively colder air stream while the other experiences a relatively warmer air stream. This causes the working fluid to maintain equilibrium by transferring thermal energy from the warmer portion to the colder portion by latent heat. This results in extremely efficient and isothermal heat transport.

Fig. 2. Air-to-Air Heat Exchanger Designed to Enhance Dehumidification Performance and Conserve Energy in a Conventional HVAC System.

An air-to-air heat exchanger can be arranged as counter- or parallel-flow. In general, counter-flow heat exchangers can obtain higher heat exchanger effectiveness values than parallel-flow heat exchangers. In other words, they are able to use more of the working fluid heat capacity than their counterpart. However, sometimes installation geometry prevents a counter-flow arrangement.

In addition, the isothermal nature of a heat pipe or thermosyphon based heat exchanger must be considered. These types of air-to-air heat exchangers consist of rows of tubes that contain a fluid at saturation. As a result, each row acts like an evaporative or condensing heat exchanger at a temperature that depends on a balance between the exhaust and supply air temperatures. As air moves through a heat pipe based air-to-air heat exchanger, the saturation temperature of each bank differs based on this balance. Unlike a typical finned-tube heat exchanger, the result is that each bank of tubes exists at a different, although isothermal, temperature.

So the type of heat exchanger described here acts like a condensing or evaporative heat exchanger relative to each row but a counter- or parallel-flow heat exchanger overall. Furthermore, in a split loop thermosyphon heat exchanger, some of the rows may be tied together. In fact, all of the rows could be tied together. However, this would result in a single temperature among all of the finned-tubes and decrease the overall effectiveness of the air-to-air heat exchanger as this arrangement reduces the available temperature potential and therefore heat capacity of the working fluid.

For this reason, the orientation of each circuit on one side of the heat exchanger relative to the matching circuit on the opposite side of the heat exchanger must be considered. The impact of temperature difference between each of the rows in the heat pipe heat exchanger is important to maximizing heat exchanger effectiveness. While there is a manufacturing benefit to combining rows of finned-tubes so that they are fed by a single manifold, this benefit must be balanced against heat exchanger performance.

ACT has developed an air-to-air heat exchanger model that optimizes the design based on parameters such as fins per inch, allowable pressure drop, thermosyphon working fluid, and temperature, flow rate, and humidity for each air stream. Based on user inputs, this model optimizes the heat exchanger design either to meet specific energy savings requirements or specific design criteria. The latter is typically used for retrofit applications.

Heat exchanger optimization is based around maximizing energy savings while minimizing the overall heat exchanger dimensions and cost. For a cooling application as shown in Fig. 3, energy savings are calculated by comparing the sensible heat lost by the supply air or gained by the exhaust air. If condensation were to occur in the supply air, the latent heat lost is also included. These savings reduce the load on the primary HVAC system thus reducing the energy consumption required to cool or heat the conditioned space. And these energy savings are provided passively.

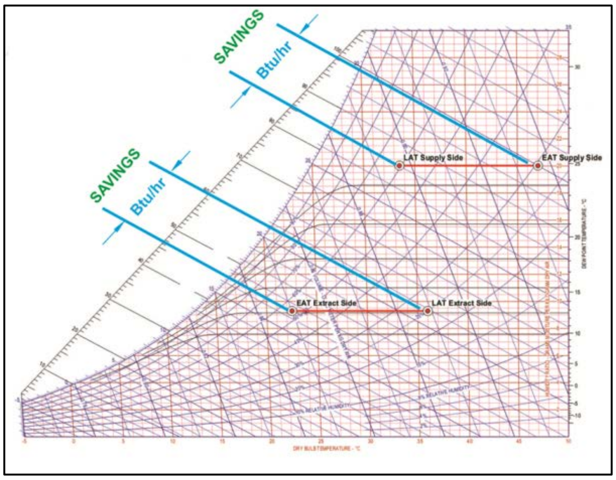

Fig. 3. Energy Savings Example for an Air-to-Air Heat Exchanger.

3. CONTROL

In some applications, control over the amount of heat transfer is desired. For example, there are some periods of time during the cooling season, when the outside air temperature dips below the temperature of the air being ventilated out of the building. The temperature difference is not too large and the air handler remains in the active cooling mode. In this scenario, the air-to-air heat exchanger would be preheating instead of precooling the incoming air, which is counterproductive. In this type of application, control valves can be added to the vapor lines of the split loop thermosyphon. The valves open and close based on the temperature difference between the exhaust air and the outside air. The building management system can also be programmed to open and close the valves for other situations where precooling or preheating of the incoming air stream is not desired. In the latter case, the valves are active and actuated by electric current.

Fig. 4 shows a split-loop thermosyphon unit with active valves. These valves shut off the air-to-air heat exchanger when energy recovery is not necessary due to outdoor conditions. ACT has also developed passive valves that rely on a phase change material to open and shut each thermosyphon circuit based on working fluid temperature. A demonstration unit using these passive valves is shown in Fig. 5.

The passive valves actuate based on the melt temperature of a phase change material. This material can be selected to provide specific set temperatures. As a result, the passive valves can be customized to their operating environment. In addition, the valves can use different melting point materials to provide a cascaded shutoff.

Fig. 4. Split Loop Thermosyphon with Active Control Valves

Fig. 5. Air-to-Air Heat Exchanger with Passive Valves that are Actuated by Phase Change Material.

4. APPLICATION

A split-loop thermosyphon heat exchanger was recently installed by ACT at a hospital facility located in Seoul, South Korea. These heat exchangers have ten rows of finned tubes, process 33 m^3/s of air, and transfer over 175kW. They are capable of offsetting approximately 60% of the heating required for the building, resulting in tremendous energy savings.

As seen in Fig 6, the manufacturing benefit of the split-loop thermosyphon is clear: linking several thermosyphon circuits using a single manifold greatly reduces the piping required to assemble the system. Furthermore, charging this system with refrigerant was simplified as, rather than charging hundreds of individually linked tubes, only approximately thirty manifolds were charged. In addition, if this system had required control, much fewer active or passive control valves would be necessary. This system has been in operation for over half a year.

Fig 6. Split Loop Thermosyphon Air-to-Air Heat Exchanger Installed in a Hospital in South Korea.

5. CONCLUSIONS

ACT has demonstrated the capability of a split-loop thermosyphon to provide significant energy savings and controllability through installation in several large scale HVAC systems. In addition, the manifold design of the split-loop thermosyphon has been shown to increase performance and simplify installation of air-to-air heat exchangers. These benefits together show a promising new application for heat pipe technology.

ACKNOWLEDGEMENT

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REFERENCES

[1] ANSI/ASHRAE Standard 62.1-2013 - Ventilation for Acceptable Indoor Air Quality