Ventilation heat recovery with run around coil: System analysis and a study on efficiency improvement – Part I

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Abstract *— A run around coil ventilation heat recovery system is analyzed in order to identify important performance factors. The aim of this investigation was to find the factors that influence the system performance, with focus on the brine side of the system. A test rig was built to provide measurements for the evaluation of the system behavior during different operating conditions. Results from measurements and calculations are presented. Three significant factors that affect system efficiency have been identified, the brine flow rate, the concentration of glycol and the charge (pressure) of the system. In addition suggestions on possible further analysis are presented to the reader. It is also concluded that for many existing systems, the heat transfer resistance may be considered to be approximately constant throughout the year even considering the fact that the outdoor temperature changes significantly.*

Keywords — Run-around coil, ventilation heat recovery, performance factors, cross-flow heat exchangers.

INTRODUCTION

In buildings equipped with large air handling units, located in cold climates with a considerable annual heat load requirements, the energy performance heavily depends on the amount of heat recovered from the extraction air. There are a number of different technical solutions available to recover heat from the extraction air, one of them being run around coils.

A run-around coil heat recovery system consists of at least two coiled heat exchangers. The coils are connected via pipes to a loop in which a fluid flows. The fluid is usually a mix of water and an anti-freeze fluid.

Run around coils is often used in buildings where contamination of the supply air is a major issue, for example hospital buildings. Run around coils is very common in Sweden, which is a country where the heat load is considerable during a large part of the year.

Since the energy performance of the buildings is dependent on the amount of recovered heat, it is important to identify the factors that influence the system performance. Previous studies [1, 2, 3, 4] have looked into parameters as how the air flow, glycol concentration, flow rate of the brine affect the overall effectiveness of these systems, most of the investigation have been simulations. However, there is very little to be found in the recent literature that describes measured data of the factors that control the performance of these systems.

In order to measure and identify these factors, a test rig has been built. The intention of the present paper is to increase the understanding of the parameters that has a major impact on the performance of run around coil heat recovery systems.

TEST SET-UP AND INSTRUMENTATION

The test facility

The test rig consists of two air handling units with cross-flow heat exchangers. One of the units is placed in a climate chamber where the temperature can be controlled between -30 °C and +50 °C. The other unit is places in the laboratory where the temperature is roughly constant around 22-25 °C. This set-up allows for test in most of the conditions that a "real" system set-up would experience. The set-up of the test rig is shown in Fig. 1.

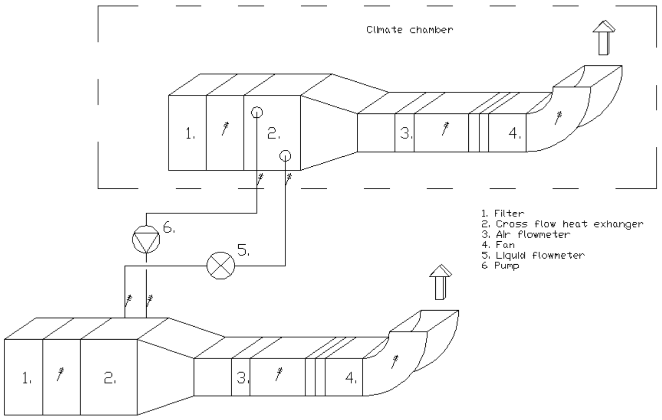

Fig. 1. Schematic of test set-up

Specifications

The two cross-flow heat exchangers (2) in the test rig are manufactured by Coiltech (QLFM-040-02-06-20-06-1). The design parameters and total heat exchanger specifications are shown in Table 1.

Table 1. Cross-flow heat exchanger data

Air	Capacity	**6.1**	kW
	Flow rate	**0.25**	m^3/s
	Temperature in	**-20**	deg C
	Humidity in	**50**	%
	Temperature out	**0.4**	deg C
	Humidity out	**8**	%
	Pressure drop	**212**	Pa
	Velocity	**2.8**	m/s
Liquid	Water with 30 % EG		
	Flow rate	**1.50**	l/s
	Temperature in	**3.5**	deg C
	Temperature out	**2.4**	deg C
	Pressure drop	**39**	kPa
	Velocity	**2.0**	m/s
Dimensions	Length finned/external	**400 / 550**	mm
	Height finned/external	**200 / 203**	mm
	External depth	**280**	mm
	No. of tube rows	**6**	
	Fin pitch	**2.0**	mm
	No. of liquid passes	**6**	
	Connection number	**DN 25**	
	Face area / Heat surface	**0.08 / 12**	m^2
	Weight / Volume	**15 / 3**	kg / l
Material	Tube material	**Copper**	
	in material	**Aluminum**	
	Header material	**Copper**	
	Casing material	**Galvanized steel**	

The two fans (4) are Systemair duct fans (K314L) equipped with thyristor speed control; they deliver a maximum flow rate of roughly 0.25 m^3/s in the test-setup. To measure the airflow, iris dampers (3) are used. Fig 2. shows the design of the dampers/air flowmeters . These are also manufactured by Systemair.

The pump (6) is a fixed speed pump that delivers a maximum flow rate of approximately 0.69 kg/s with water as a heat transfer liquid. The flow rate in the system is controlled with a manual regulating valve.

To measure the flow rate of the liquid a Siemens Sitrans FM (5) is used. The flow meter was calibrated on delivery and the calibration was verified using time-weight technique.

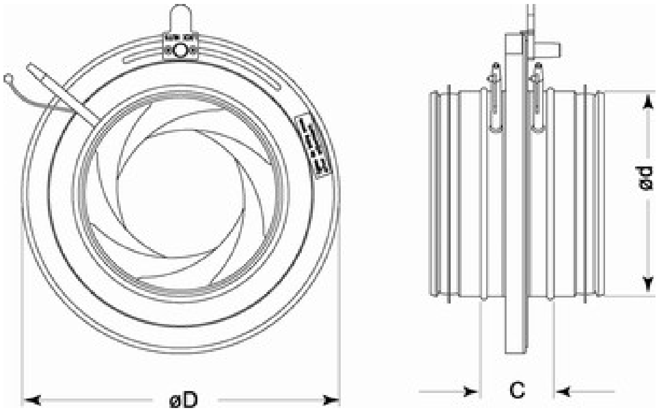

Fig 2. Iris damper/air flowmeter.

Temperatures are measured on ten locations with twenty thermocouples type T. The locations are strategically selected and several thermocouples are used in some points to provide accurate readings. The thermocouples were calibrated together, in the range of 0 °C to 100 °C, before installation.

All the measuring equipment is connected to an Agilent 349070A data acquisition unit and readings were taken every 10 second during the measurements; the readings were stored on a computer communicating with the Agilent unit.

Experiments

Experiments were carried out with the conditions described by table 2.

Table 2. Summary of different test conditions

Brine	**Different flow rate of brine side**	**Different climate chamber temperatures**	**System pressure/ brine filling**
Water	X	—	X
Water/glycol 26%	X	X	—
Water/glycol 49%	X	—	—

Testing started with water as brine and the temperature in the chamber was set to 40 °C; the temperature on the outside of the climate chamber was approximately 24-25 °C throughout the tests. The flow rates on the brine and air sides of the cross-flow heat exchangers were kept constant and readings were taken every 10 second during a 20 minute time period. Testing was carried out in the same fashion with several different flow rates of the brine in order to analyze the behavior of the system. After the test was completed with water, the system was drained, cleaned and dried by flushing it with fresh water and forcing pressurized air through the loop. The system was then filled with a mix of water/ ethylene glycol mix (49 %) and later a different mix of ethylene and glycol (26%). The system was filled to a pressure of 2 bar every time. The same test procedure as for the water was the carried out for the different water/ ethylene glycol solutions. The flow rate of the air side was kept constant throughout the testing. With the test data the UA-value for the two heat exchangers were calculated to evaluate the performance of the system and also give the correlations for the future models of the cross-flow heat exchangers. The results of the change in UA-value depending on the flow rate and of the different brine solutions are shown in Fig. 3a and Fig. 3b.

The next step in the experiments was to analyze how the difference in temperature in the climate chamber affects the UA-value of the two cross-flow heat exchangers. For this case four different temperatures was used in the climate chamber; - 5 °C, 0 °C, 5 °C, 10 °C. These temperatures cover the majority of the operation hours of the system during one year. One brine solution was used for this test; water/ ethylene glycol 26 %. Several different flow rates of the brine were tested for three of the temperatures, for the 0 °C experiments only one flow rate was tested.

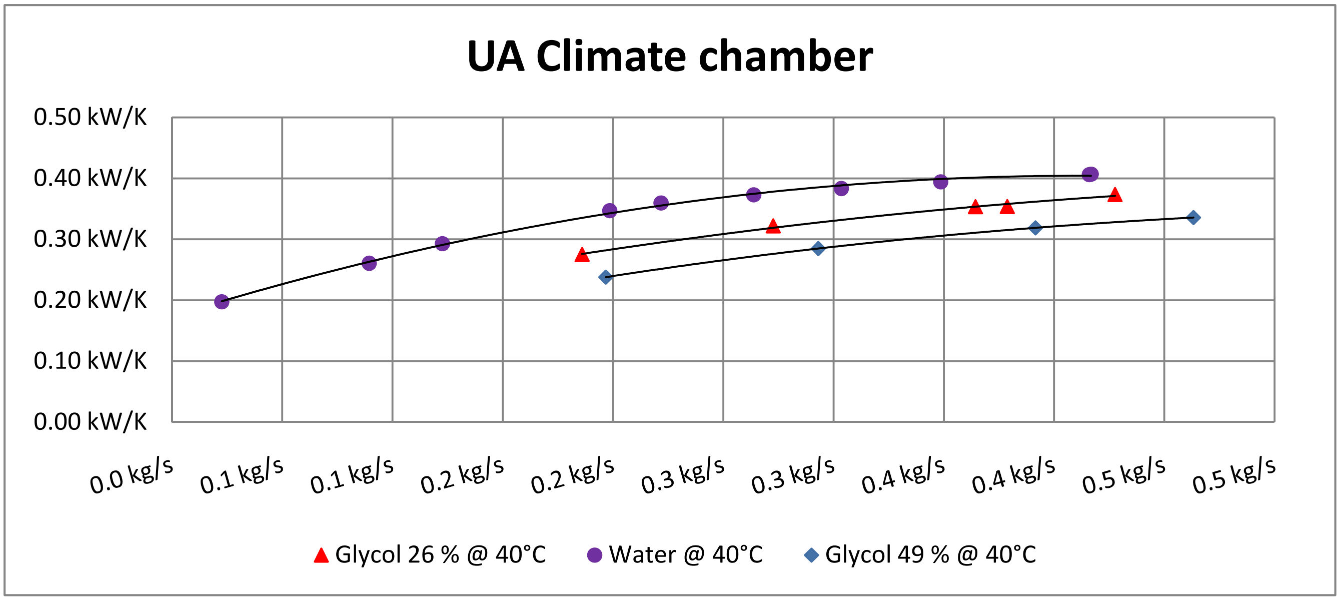

Fig. 3a. UA-values for cross-flow heat exchanger in climate chamber at different brine flow rates

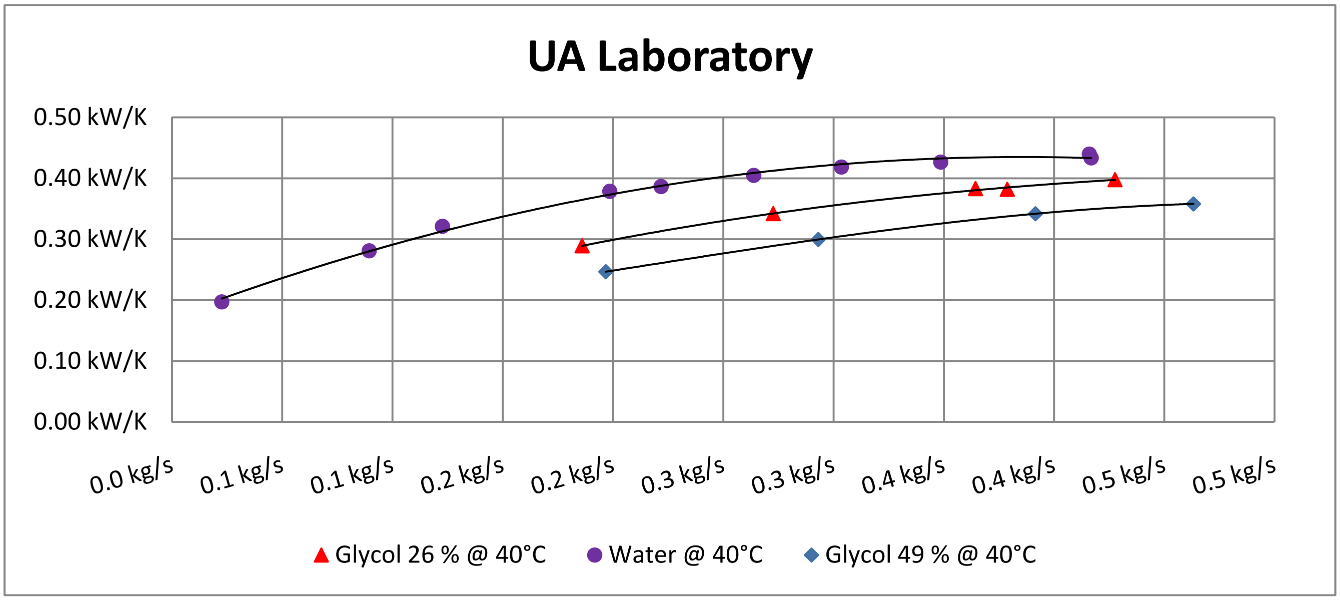

Fig. 3b. UA-values for cross-flow heat exchanger in laboratory at different brine flow rates.

The results from the experiments are shown in Fig. 4a and Fig. 4b.

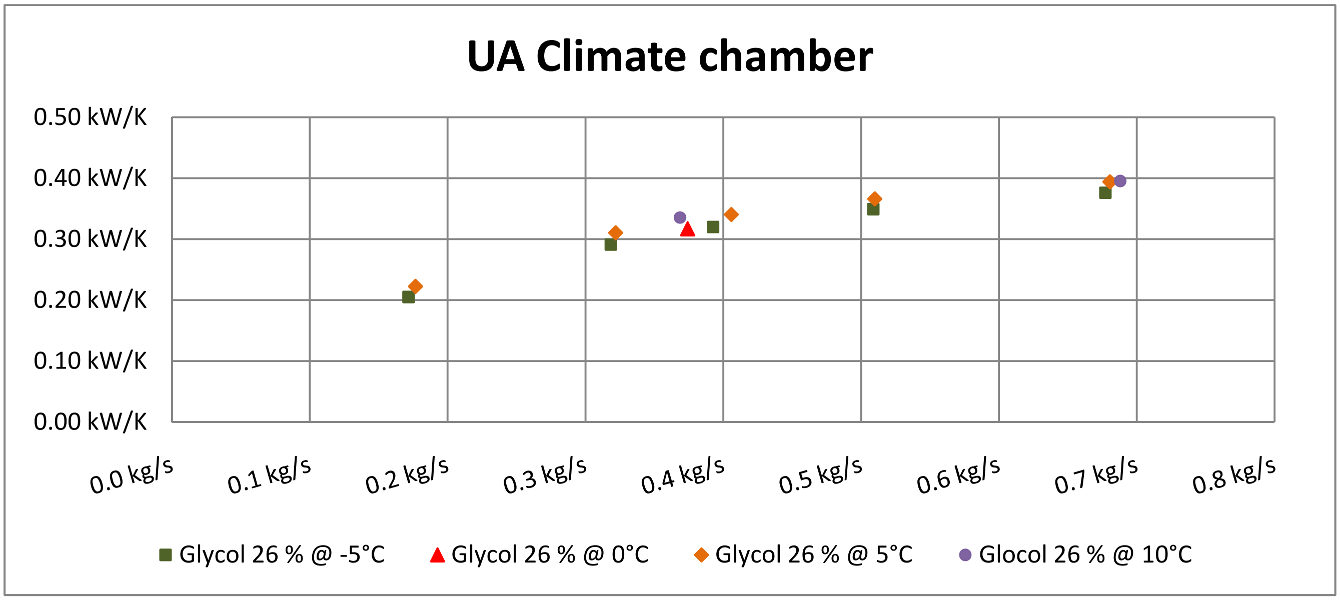

Fig. 4a. UA-values for cross-flow heat exchanger in Climate chamber at different temperatures and brine flow rates.

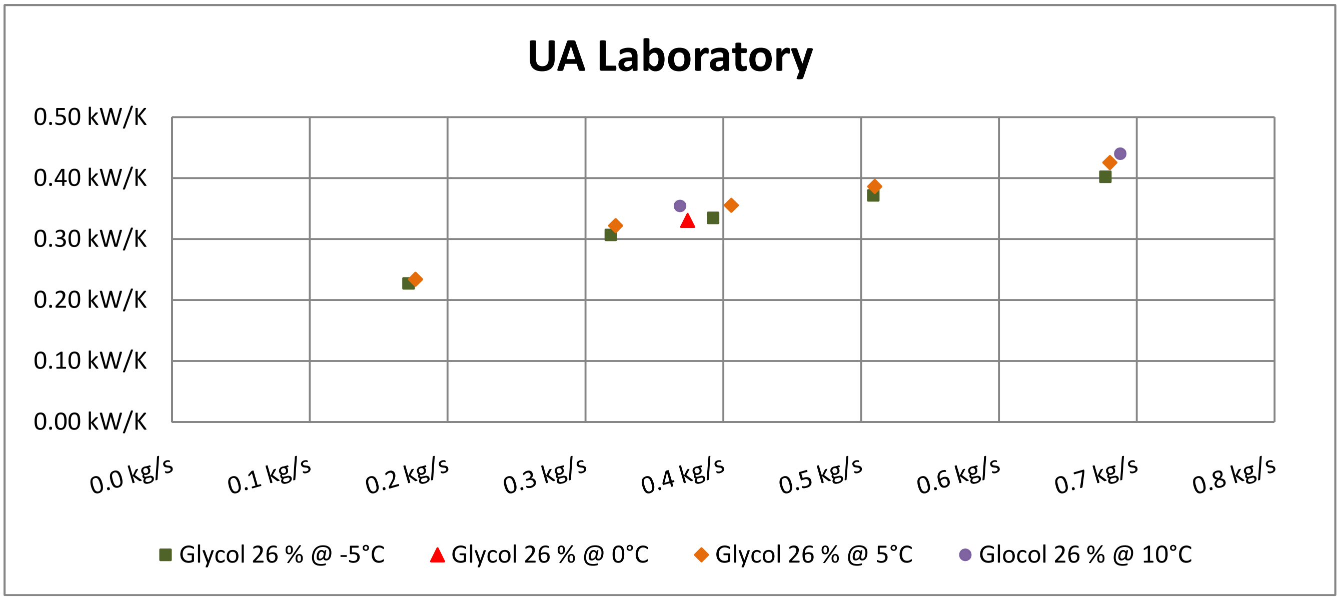

Fig. 4b. UA-values for cross-flow heat exchanger in laboratory at different temperatures and brine flow rates.

The third area of investigation was how the charge of the brine side affected the performance of the system. The system was again drained, cleaned and dried using the same approach as previously described. The system was then charged from a tank that was weighed before and after to conclude the amount of charge. The amount of charge to get the system up to 2 bars of pressure was 18.22 kg of water/ethylene glycol. The system was then drained little by little and readings were taken every 10 seconds during a 20 minute time period for each pressure level. The other system parameters were left untouched during the testing. The different levels and results are shown in table 3.

Table 3. Summary of data for different charge levels.

Run	Pressure	Charge	Charge	Rate of recovery
1	2.0 Bar	18.22 kg	0	1.79 kW
2	1.5 Bar	17.45 kg	95.8%	1.73 kW
3	1.1 Bar	16.62 kg	91.2%	1.67 kW
4	1.0 Bar	15.75 kg	86.4%	1.71 kW
5	0.8 Bar	15.11 kg	82.9%	1.75 kW
6	0.7 Bar	14.57 kg	80.0%	1.58 kW
7	0.6 Bar	13.94 kg	76.5%	1.52 kW
8	0.5 Bar	13.22 kg	72.6%	1.48 kW
9	0.4 Bar	12.25 kg	67.2%	1.43 kW
10	0.3 Bar	11.33 kg	62.2%	1.23 kW
11	0.2 Bar	10.08 kg	55.3%	0.93 kW
12	0.0 Bar	7.76 kg	42.6%	0.21 kW

TEST RESULTS

The first test shows that the flow-rate of the brine is affecting the performance of the system. The impact of change in flow rate in run-around coil systems was previously analyzed by Emerson [1] with the conclusion that there is an optimum flow rate for these systems. However Emerson does not investigate the magnitude of change in the rate of recovery. The present investigation did not find an optimum flow rate; this may indicate that the optimum flow rate for the system is higher than what the pump can deliver. However the experiments clearly show that the flow rate of the brine has an impact on the system performance.

Concentration of ethylene glycol also has an impact on the system performance. The experiments indicates that the impact of the glycol dependent on both the concentration and on the flow rate. See Fig. 3a and Fig. 3b.

Tests with different climate chamber temperatures leads to the assumption that the UA-value can be considered to be air temperature independent; this can be true if the change of the air temperature is moderate (at least up to a 15 K temperature difference). This air temperature interval covers the majority of the operational hour of this kind of system in Sweden and even more so in central parts of Europe. This finding could be important when estimating existing systems annual performance, since the air flow rates only changes modestly over the year. Many systems also operates with constant brine flow rate, hence the overall UA-value of each of the heat exchangers could be assumed to be approximately constant throughout the year, greatly simplifying the analysis.

The experiments with the charge indicate that it is important to the performance of the system. Pressure decreases rapidly in the beginning when the charge is reduced and when the charge is at 70 % or 0.7 bar, the system performance has clearly started to be reduced. How the rate of heat recovery is changed with the reduction of charge is shown in Fig. 5.

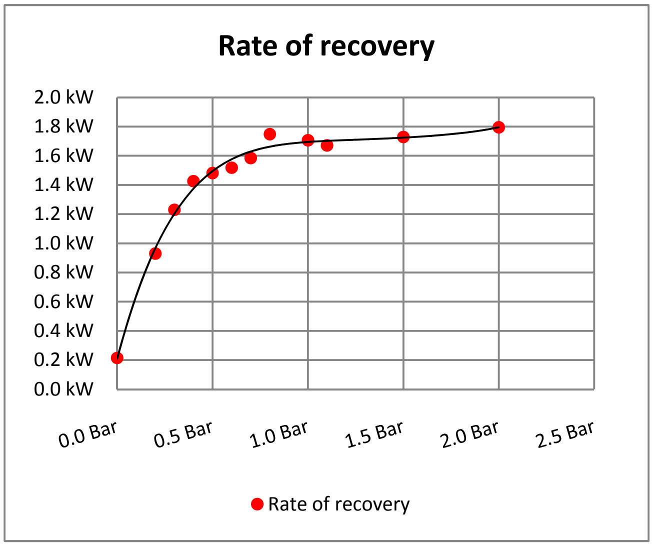

Fig. 5. Rate of recovery dependent on the system pressure

SUMMARY AND DISCUSSION

The experiments were undertaken to obtain knowledge regarding the key factors for the system performance but also provide information on how to evaluate existing systems in the future. This is a work in progress and the results so far are that there are several factors on the brine side that influences the system performance of a run-around coil heat recovery system; the experiments have so far revealed three factors:

- **Flow rate of the brine.** The present paper concludes that this can be an important factor; this is especially true if the flow rate is low. The reason for this is that the heat transfer resistance is increasing with reduced Reynold numbers. Emerson [1] suggested that there is always an optimum flow rate for a run-around coil system that is unique to every system. Forsyth and Besant [2] presented that there is no maximum effectiveness for the system that is dependent on the flow rate. The experiments presented in the present paper points in the direction of what Forsyth and Besant [2] presented. In future work a new pump will be fitted to enable us to investigate the effects of higher flow rates.
- **Concentration of ethylene glycol.** The introduction of the anti-freeze ethylene glycol to the system decreases

the system performance. The magnitude of the difference of heat recovery rate between water as the reference liquid and water/ ethylene glycol brine is dependent on both the flow rate and the concentration of ethylene glycol. The introduction of glycol is influencing the viscosity of the brine and therefore lowering the Reynold number. This affects the heat transfer resistance between the brine and the pipe wall, the reason for the decrease of system performance is therefore the same as for the flow rate parameter.

- **Charge (pressure) of the system.** In existing systems with sealed expansion tank it is not uncommon that the pressure is lower than the design pressure. The reason could for example be small leaks or that there are no clear instructions what the design pressure is. This test is an attempt to find out how the system performance is affected by the decreases in system pressure. It is important to know the impact that a low charge of these systems will have when the energy use of the air handling unit shall be evaluated. The experiments showed that the flow rate of the brine is reduced when the system pressure decreases. This is one factor that leads to a reduction in recovered heat, however this probably not the only reason that the heat transfer rate that is decreased. Experiments show that the decrease in heat recovery rate starts at a relatively low reduction of charge. From about 70 % of charge there is a clear trend of a lower heat recovery rate.

FURTHER WORK

For further work there are a few interesting things that may be studied further. The effects of a higher flow rate of the brine fluid is one thing that could be worthy to look into, and with that finding the influence of the pumping power to conclude if there is a optimum flow rate for the total system performance. There is also a potential to look into how the air side fouling is affecting the overall performance. It would also be interesting to build a model to simulate the overall system performance to find the optimum design for this system type.

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