Revisions to the Design of the Cooling Systems for the MVD

by

Jan Boissevain

1. Overview of Proposed Changes to the MVD Cooling System

The proposed cooling system, as detailed in the report "Design Report of the Cooling Systems for the Multiplicity and Vertex Detector" [1], requires 5 chillers. There is not enough available room in PHENIX for this solution. This space constraint forced the consideration of a combined system, which uses 3 chillers and 2 fan units [figure 1]. The report [1] uses data from the prototype cooling system. The cooling lines of the prototype were not insulated. Addition of insulation around the cooling lines will result in significant savings in the required chiller capacity. This modified cooling system proposal combines air system 1 (which cools the central plenum of half of the MVD) and air system 2 (which cools half of the MVD enclosure). The Sonic blower can supply adequate air flow for both systems since the limiting factor is the output pressure of the fan unit. It is now known that there is space for a larger air/water heat exchanger than the unit specified in report [1]. These heat exchangers reduce the temperature difference between the chilled water and the circulating air and they can handle the higher flow rates required by the combined system. In addition, different temperature and flow sensors have been chosen to better match the recently completed conceptual design of the MVD Ancillary Control System.

2. Heat Load Reduction due to Added Insulation to Cooling Lines

In the prototype, the air-cooling lines were not insulated. The largest heat load is on the air-cooling supply tube. This tube has a 5 cm inside diameter and is 5 meters long. The tube wall thickness, '*t*', is 0.6 cm.

Formulas:

$Q = h_1 A_1 \Delta T_1$ heat exchange at the outer surface of the tube

$Q = k \frac{A_{avg}}{t} \Delta T_2$ thermal conduction through tube wall

$Q = h_2 A_2 \Delta T_3$ heat exchange at the inner surface of the tube

Assume:

$\Delta T_1 + \Delta T_2 + \Delta T_3 = 30\,°\mathrm{C}$

$h_1 = \frac{30W}{m^2 °C}$ typical air to surface heat exchange for laminar flow at STP

$h_2 = \frac{60W}{m^2 °C}$ typical air to surface heat exchange for turbulent flow at STP

$k = \frac{.2W}{m°C}$ thermal conductivity of plastic cooling tube

$A_1 = \pi(.062m)(5m) = .97m^2$ .062m is the O.D. of the cooling tube

$A_2 = \pi(.05m)(5m) = .79m^2$ .05m is the I.D. of the cooling tube

$A_{avg} = \pi(.056m)(5m) = .88m^2$

Then:

$$Q = h_1 A_1 \Delta T_1 = k \frac{A_{avg}}{t} \Delta T_2 = h_2 A_2 \Delta T_3$$
$$Q = \frac{29.1W}{°C} \Delta T_1 = \frac{29.3W}{°C} \Delta T_2 = \frac{47.4W}{°C} \Delta T_3$$
$$2.6 \Delta T_1 = 30°C$$
$$\Delta T_1 = 11.5°C$$
$$Q = 334W$$

This heat load is consistent with the head load of the MVD adapters and channels (200W) and the heat load of the tubing (60W), as described in reference [1].

Calculate for the case where the cooling tube is insulated with 2.5 cm of plastic foam. In this case, the inside diameter of the tube is 6.35 cm and the wall thickness is 0.15 cm. The length is 5 meters.

Formulas:

$Q = h_1 A_1 \Delta T_1$ heat exchange at the outer surface of the insulation

$Q = k_1 \frac{A_{avg}}{t_1} \Delta T_2$ thermal conduction through the insulation

$Q = h_2 A_2 \Delta T_3$ heat exchange at the outer surface of the tube

$Q = k_2 \frac{A_{avg2}}{t_2} \Delta T_4$ thermal conduction through the tube wall

$Q = h_3 A_3 \Delta T_5$ heat exchange at the inner surface of the tube

Assume:

$\Delta T_1 + \Delta T_2 + \Delta T_3 + \Delta T_4 + \Delta T_5 = 30°C$ worst case condition

$h_1 = h_2 = \frac{30W}{m^2 °C}$ typical air to surface heat exchange for laminar flow

$k_1 = \frac{.036W}{m°C}$ thermal conductivity of the plastic foam insulation

$k_2 = \frac{.2W}{m°C}$ thermal conductivity of plastic cooling tube

$h_3 = \frac{60W}{m^2 °C}$ typical air to surface heat exchange for turbulent flow

$A'_1 = \pi(.117m)(5m) = 1.8m^2$

$A'_{avg1} = \pi(.089m)(5m) = 1.4m^2$

$A'_2 = A_{avg2} = A_3 = \pi(.064m)(5m) = 1.0m^2$

$$Q = h_1 A_1 \Delta T_1 = k_1 \frac{A_{avg1}}{t_1} \Delta T_2 = h_2 A_2 \Delta T_3 = k_2 \frac{A_{avg2}}{t_2} \Delta T_4 = h_3 A_3 \Delta T_5$$

$$Q = \frac{54W}{°C} \Delta T_1 = \frac{2W}{°C} \Delta T_2 = \frac{42W}{°C} \Delta T_3 = \frac{133W}{°C} \Delta T_4 = \frac{60W}{°C} \Delta T_5$$

$$30.6 \Delta T_1 = 30°C$$

$$\Delta T_1 = .98°C$$

$$Q = 53W$$

The above calculation is for air system 1 (MCM cooling). For air system 2 (enclosure cooling), the tubing has a diameter of 3.2 cm. Under the same assumptions as for air system 1 with insulated tubing, the heat load from the air system 2 tube is 33W. The combined system also cools the motherboard coolant (FC75). A conservative assumption for the efficiency of the LDOs is >80%. A MCM consumes less than 4 Watts of power – less than 272 Watts for half of the MVD. The heat generated by the LDOs will be no greater than 20% of 272 Watts (54 Watts). In addition, there will be some heat load associated with the experimental hall environment. Assuming that the cooling tubes are insulated, the combined system cooling budget becomes the following:

- Heat load of MCMs = 68 MCMs at 4 W/MCM: ----------------------------------272 W
- Heat load of air blower (approximated): --60 W
- Heat load of air system 1 tubing (calculated): ---53 W
- Heat load of MVD enclosure (1/2): ---100 W
- Heat load of air system 2 tubing (calculated): ---33 W
- Heat load of LDOs of two motherboards and tubing: -------------------------------- 70 W

Total Heat Load = 588 W

3. Heat Exchanger Choice

The design report [1] specified two Lytron 6110 heat exchangers in series with the air flow. These units are very compact with a thermal performance of 17 Watts/°C assuming 0.5gal/min water flow and 50CFM of air flow. The next larger size heat exchanger is the 6210. This unit has a thermal performance of 60 Watts/°C assuming 0.5 gal/min and

100CFM of air flow. For a 600 Watt heat load and two 6210 heat exchangers, the temperature difference between the chilled water and the air would be approximately 5°C. For an air temperature of 8°C at the output of the heat exchanger assembly, the refrigeration capacity must be greater than 588 Watts at 3°C. The proposed chiller (FTS Systems RS44LT) is rated at 760 Watts at 0°C. The heat exchanger design is shown in figures 2 and 3.

Figure 1: MVD Cooling Schematic (1/2 MVD)

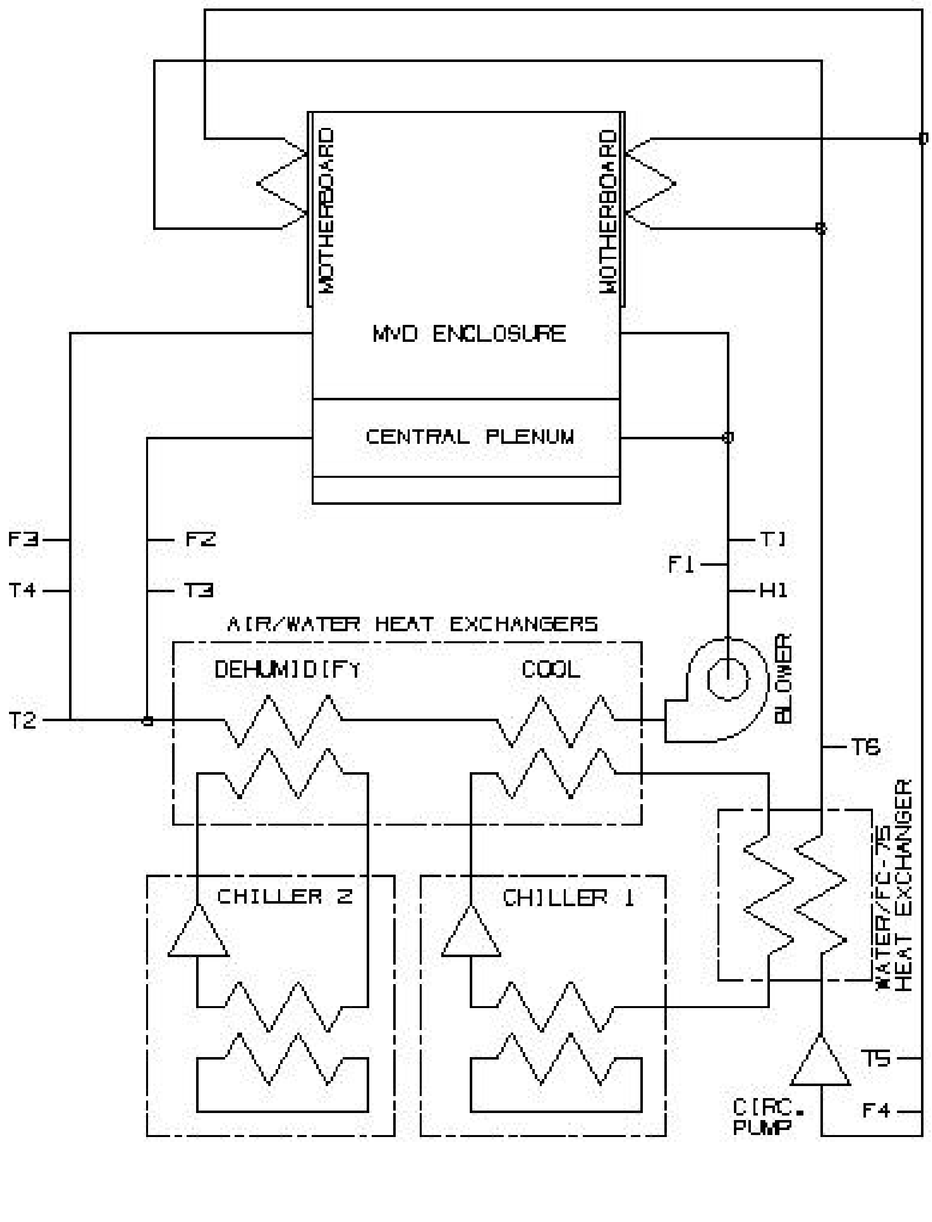


Figure 2: MVD Heat Exchanger Assembly

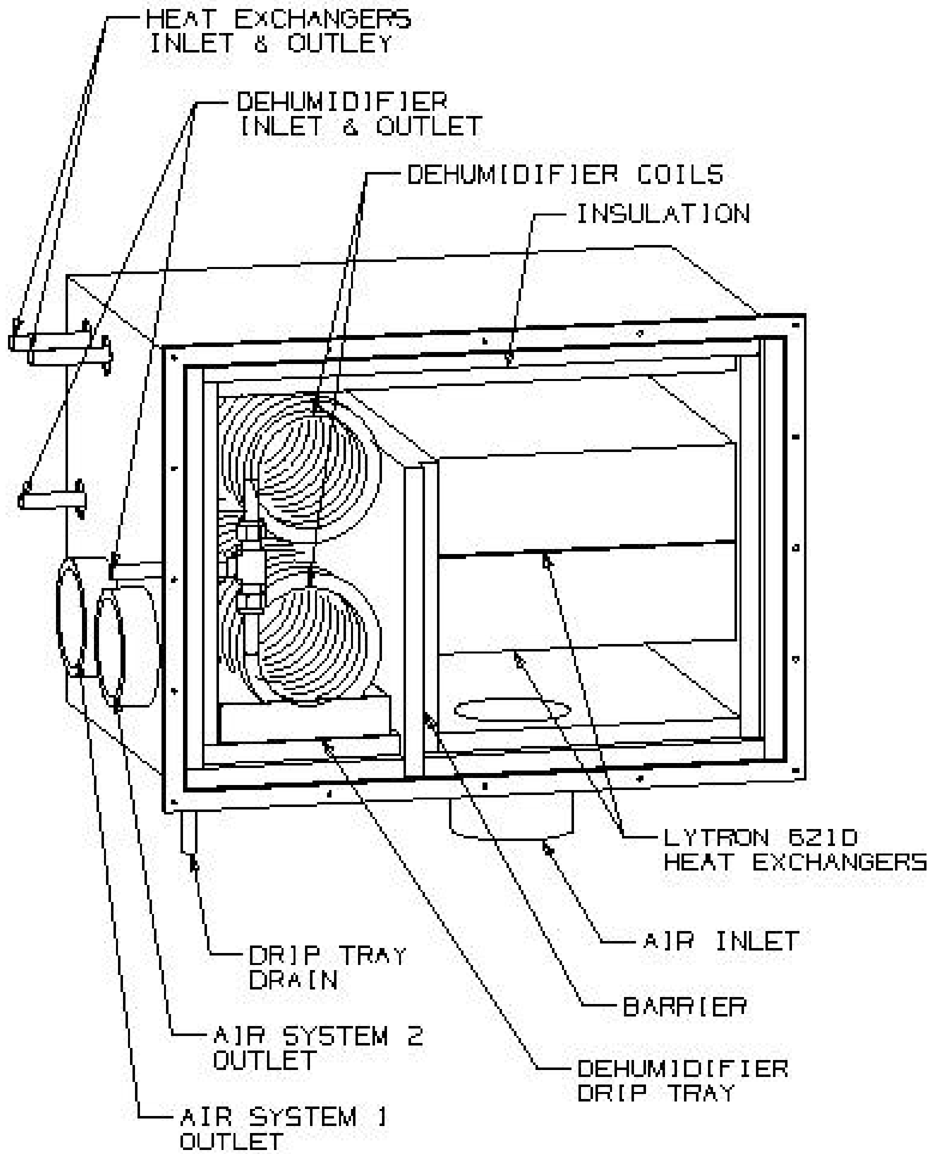
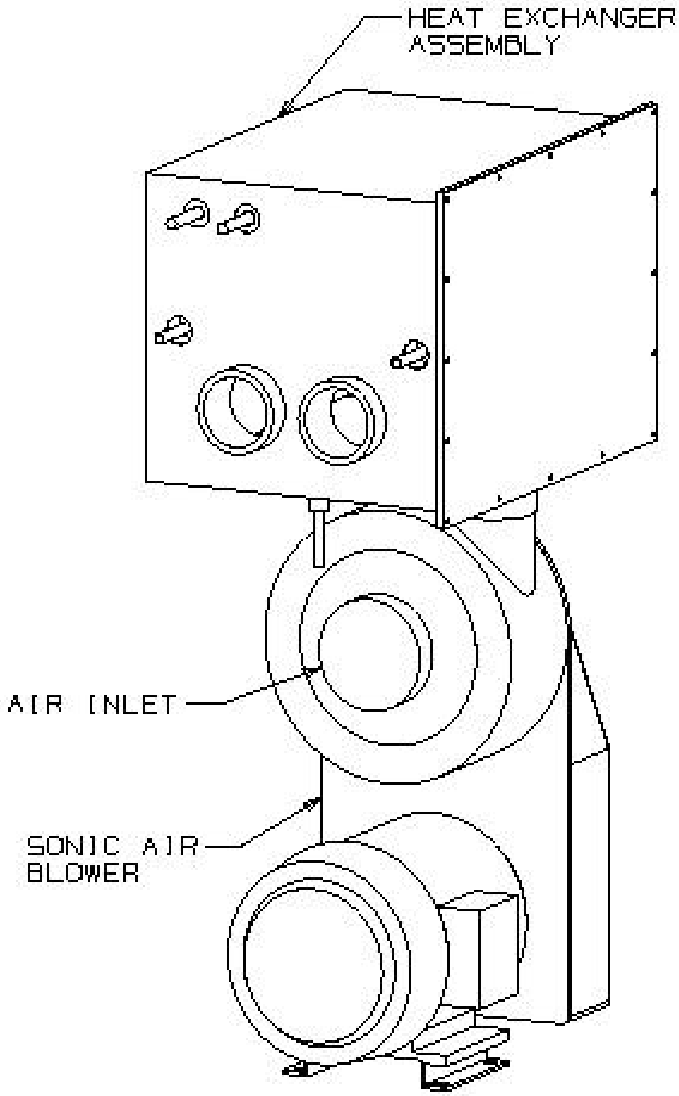


Figure 3: MVD Air Cooling System Assembly



4. Components and Costs List

Itemized list of components for the MVD cooling system (this does not include prices for spare parts or backup components).

Item	Supplier, Catalog No., Comments	Unit Cost (No tax or shipping)	Quantity	Total Cost ($)
Air blower	Sonic Air, SAS-700, Motor = 3 hp, Gearing: 15,000RPM Mean time between failures = 10 to 12 K h, Bearing life = 14 K h, Drive belt = 6 K h, Motor life = 5 to 7 y	2,900	2	5,800
Water chiller	FTS Systems, RS44LT, Standard centrifugal pump with water flow = 2 gpm at 6 psi Cooling capacity = 760 W at 0°C,	3,000	3	9,000
Heat exchanger	Lytron, 6210, Lytron to supply heat exchanger cores. A machine shop vendor is required to fabricate heat exchanger casing.	183	4	732
Air flow sensor/controller F1-F3	Analog Devices Model # TMP12 Resistor programmable temperature setpoints 100 ohm heater	6	6	36
Temperature sensor T1,T2,T5,T6	Analog Devices Model # AD590 1μA/°K	8	4	32
Temperature sensor/controller T3,T4	Analog Devices Model # ADT14 5mV/°C 4 resistor programmable temperature setpoints	4	6	24
Humidity Sensor H1	Omega Engineering Inc Model # HX49-D-V Range: 0-100% humidity Duct mount 0-5 V output 12-40 V input	295	2	590
Liquid Flow Sensor/Switch F4	Omega Engineering Inc Model # FPR121 .1 to 1.0 GPM – low range	135	2	270

	.5 to 5.0 GPM – std range			
Liquid Level Sensor/Switch	Omega Engineering Inc Model # LV171 Optical liquid level sensor	110	2	220
Liquid Flow Sensor/Switch F4	Omega Engineering Inc Model # FPR121 .1 to 1.0 GPM – low range .5 to 5.0 GPM – std range	135	2	270
Liquid Circulating Pump	Grainer Model # 2P041 1 GPM @ 24' head 12 GPM @ 12' head	158	2	316
Tubing and fittings	Accurate Plastics, Albuquerque Valve and Fitting, Co.,			
Total				(17,290)

References

[1] Bernardin, J. D., Cunningham, R., *Design of the Cooling Systems for the Multiplicity and Vertex Detector*, PHENIX-MVD-97-44, PHENIX Note #330.