Carbon Dioxide Refrigeration System
For
Server-room Application

CONTENTS

1. INTRODUCTION

In this study, a CO_2 refrigeration system for server room application was modelled using EES. Refrigeration system operates under three different modes for different temperature ranges. For low ambient temperatures, free cooling is utilized, which is a single stage CO2 cycle. Presently system has been modelled only for subcritical region of the CO_2 cycle. For medium ambient temperatures, propylene is used as secondary refrigerant and some of the CO_2 from the receiver is let through a three way valve to propylene chiller as can be seen in the process diagram in figure 1. For higher ambient temperatures in summers, all the CO_2 flow is directed through propylene chiller and cooling takes place via propylene chiller alone. All three different modes of operation of cooling system were modelled separately and description of these models along with the results has been elaborated in subsequent sections. In entire study, hot air is assumed to be available at a fixed temperature of 40^{0}C and cooling system has been modelled with a cooling capacity of 1MW.

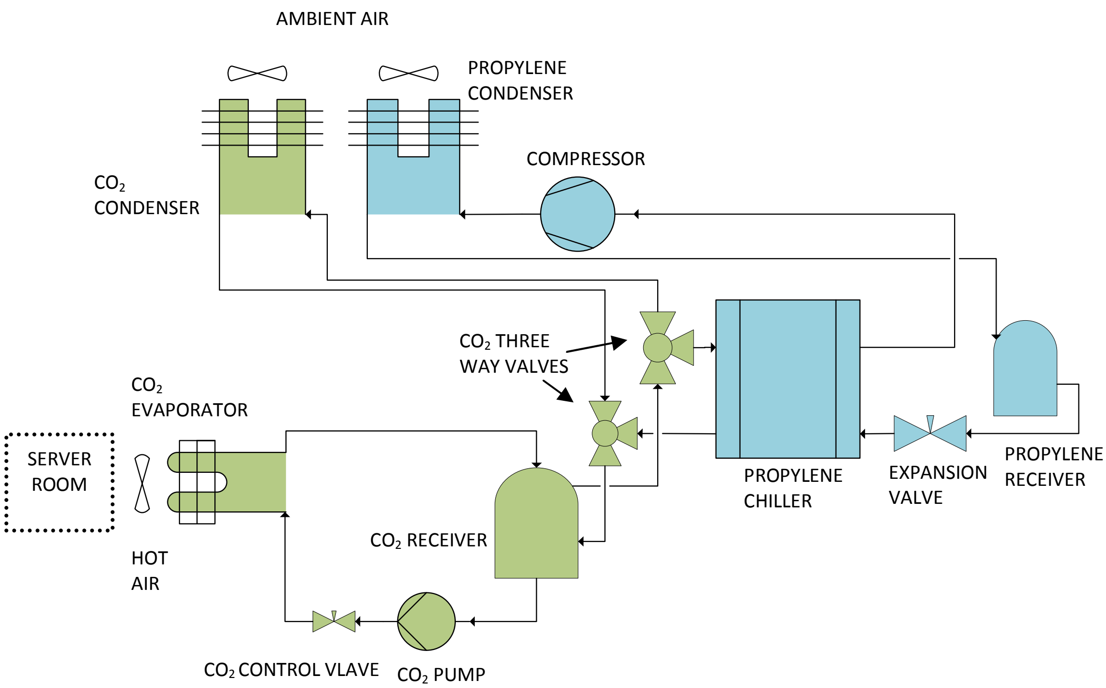

Figure 1. Process diagram for the cooling system

2. **FREE COOLING**

Free cooling operates entirely on CO_2 without need for a secondary refrigerant and significant amount of energy savings are obtained due to obliteration of compressor power input to the system. The diagram in figure 2 depicts the simple free cooling cycle. System modelled is suitable for ambient temperature range of 1 to 7 ^{0}C. Model autometically sets the evaporation and condensation temperatures based on ambient temperature input to the model and results has been plotted in figure 4 for entire range of operation of free cooling cycle. Superheat for evaporator was set to +2^{0}C.

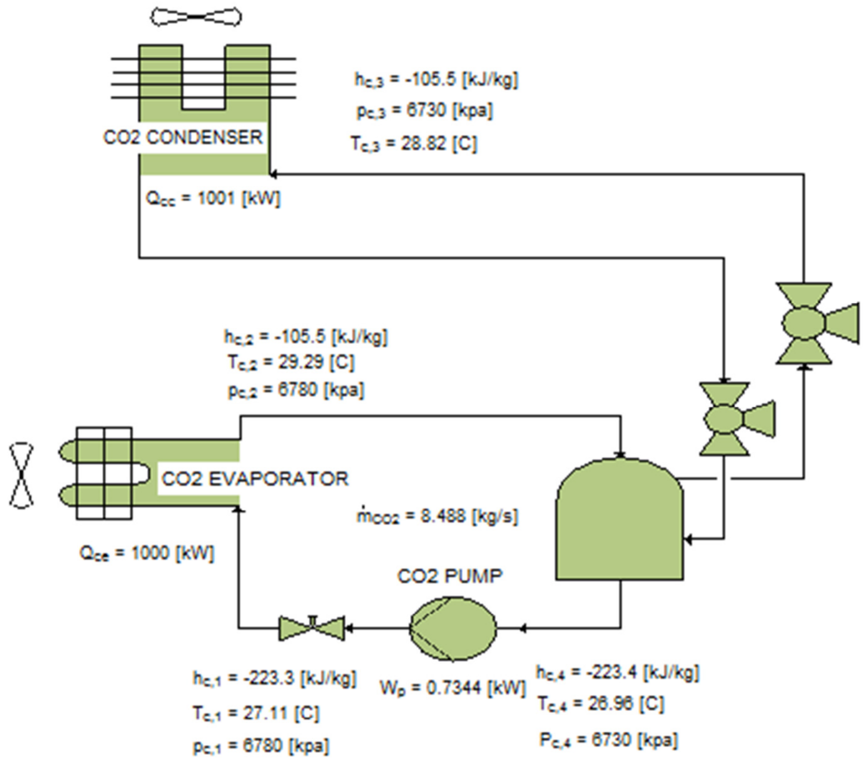

Figure 2. Model for Free cooling.

Figure 3 shows p-h diagram for carbon dioxide cycle for an ambient temperature of 7^{0}C. The pump work input and refrigerant flow rate are given in figure 5 and figure 6. The hot air flow rate across CO_2 evpoator was set by the model for different ambient temperature values for a constant cooling capacity through out the operating range of free cooling cycle. System works for temperaturs till 7^{0}C although the hot air flow rate values required to maintain 1MW cooling capacity are not realistic. UA vlaues for CO_2 evaporator and condenser were set to be 92 and 338 kW/K respectively whereas ambient air flow was set at 50 kg/s.

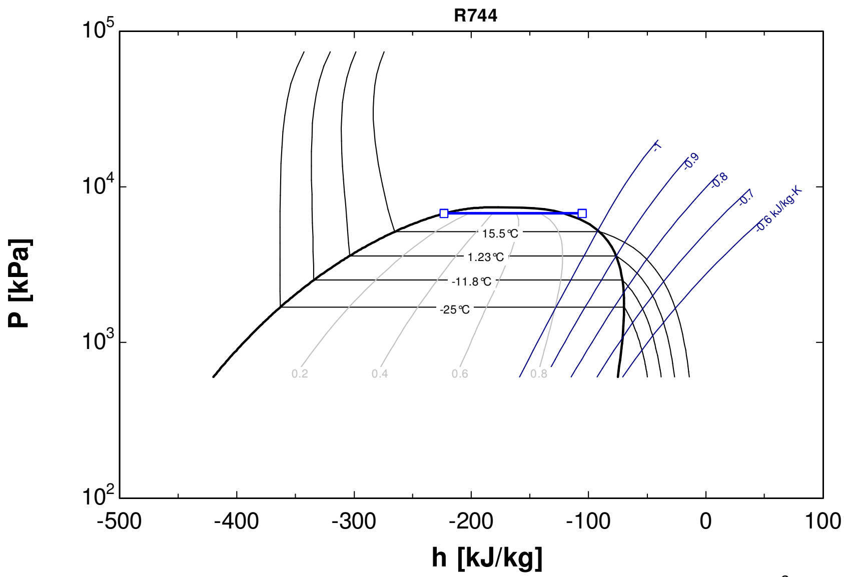

Figure 3. Carbon Dioxide Cycle for Ambient air Temperature of 7^0C

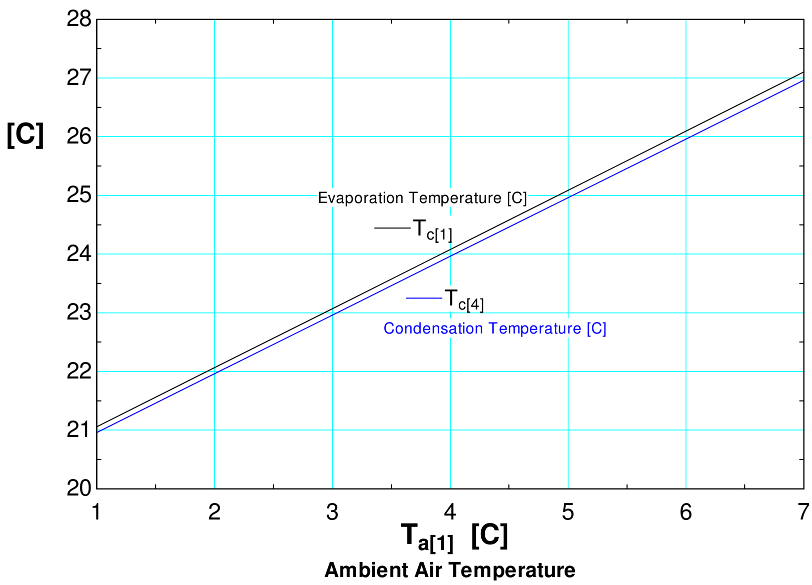

Figure 4. Variation of Evaporation and condensation temperatures for ambient air temperature range for free-cooling

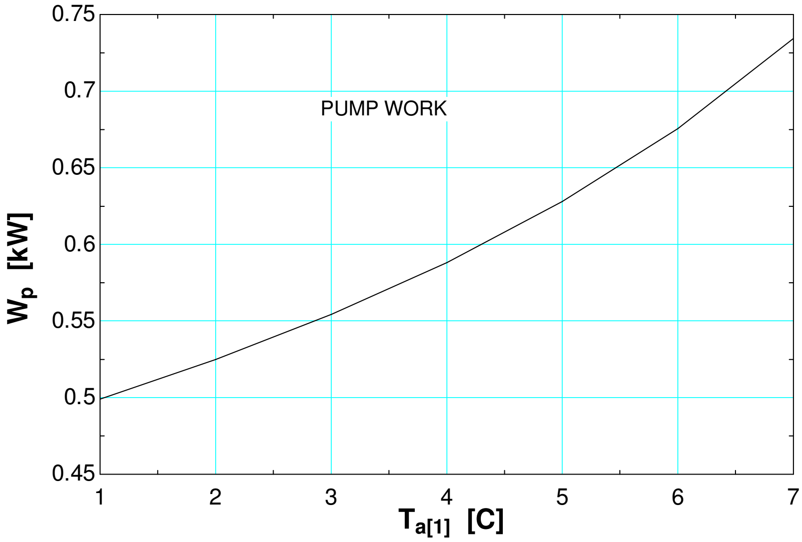

Figure 5. Pump Work for free cooling

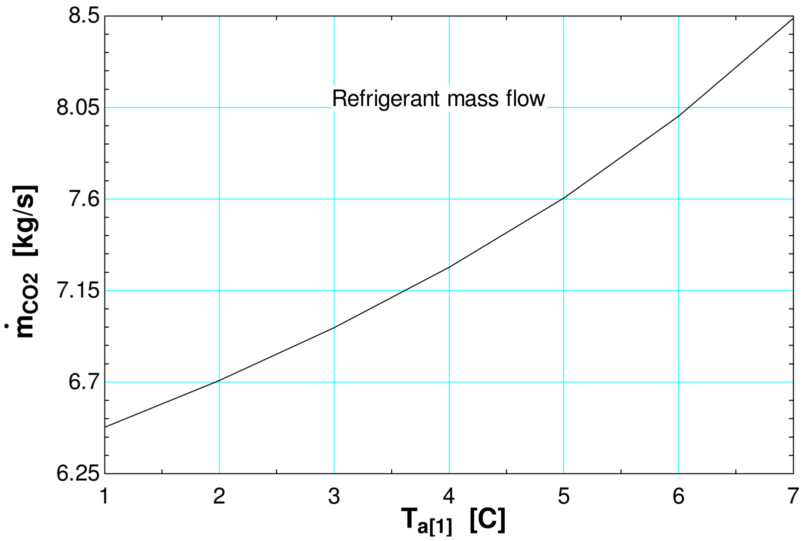

Figure 6. Refrigerant mass flow rate for a cooling capacity of 1MW

3. Hybrid Cooling:

The operation of cooling system is switched to hybrid cooling cycle for temperatures more than 7^{0}C. In this operation, CO_2 cycle is used at its full capacity and rest of the CO_2 flow is directed to propylene cycle through a propylene chiller as given in figure 7. The CO_2 is cooled to 19^{0}C in propylene chiller and this temperature has been fixed for ambient temperature range of operation.

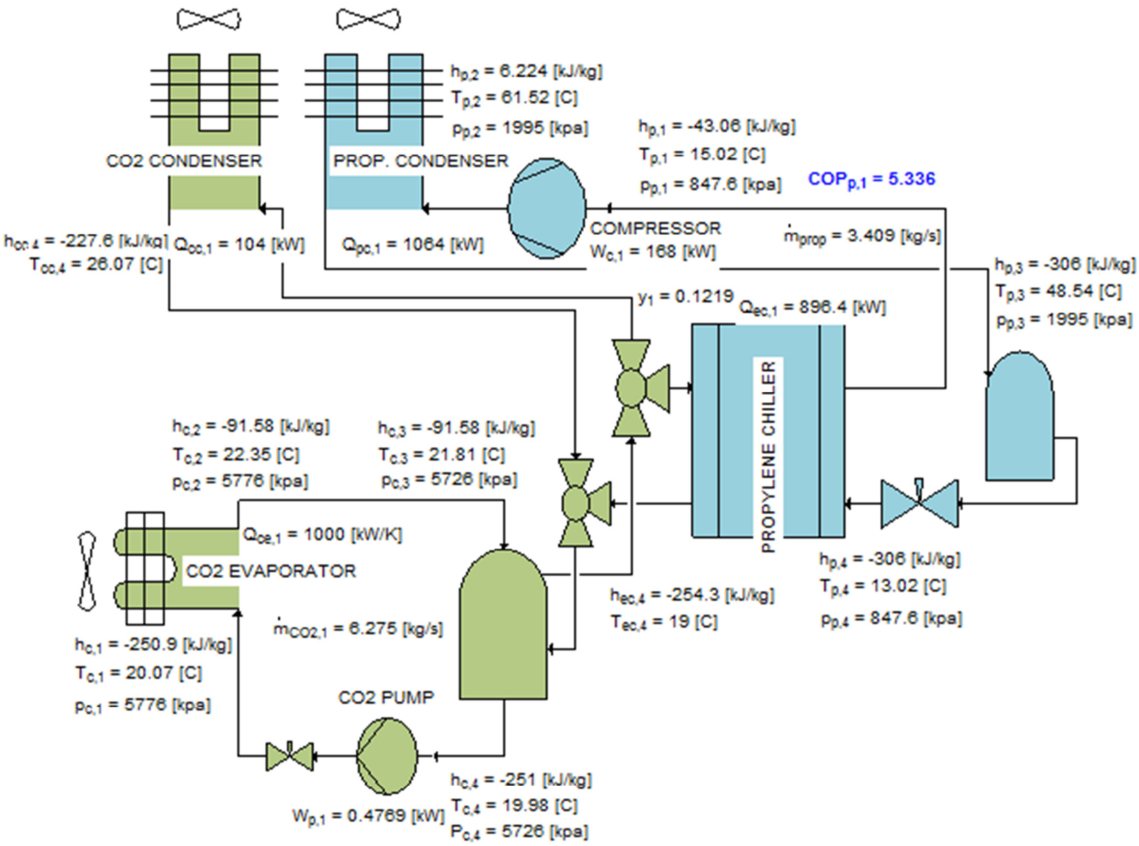

Figure 7. Model for hybrid cooling cycle

Same UA values for CO_2 circuit and air flow rate stated in previous section have been used for the present model. UA values for propylene chiller and propylene condenser have been set as 150 and 338 kW/K respectively. Hot air flow rate has been fixed at 67 kg/s. The model was allowed to run till all the capacity of CO_2 cycle was exhausted which occurs for an ambient temperature of 24^{0}C. The p-h diagrams for individual CO_2 and propylene cycles have been plotted on the following page (figure 8 and 9).

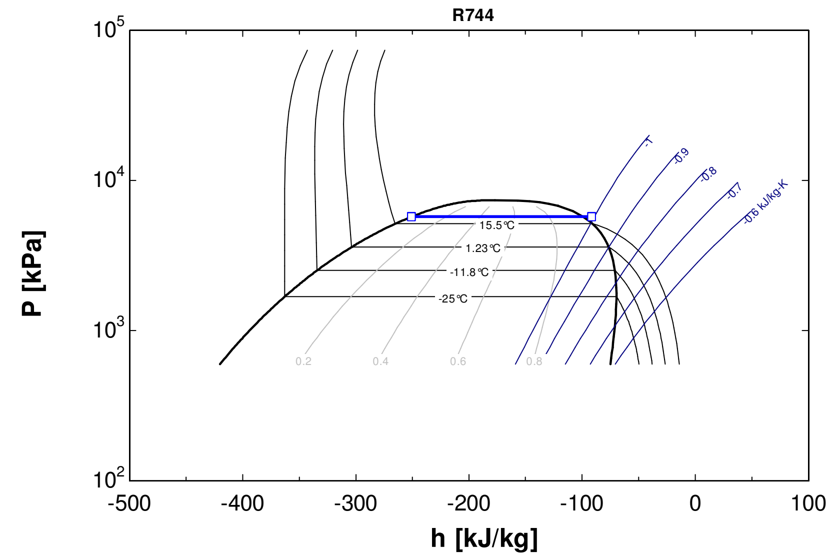

Figure 8. Carbon Dioxide cycle for Hybrid cooling at ambient air temperature of 24^{0}C

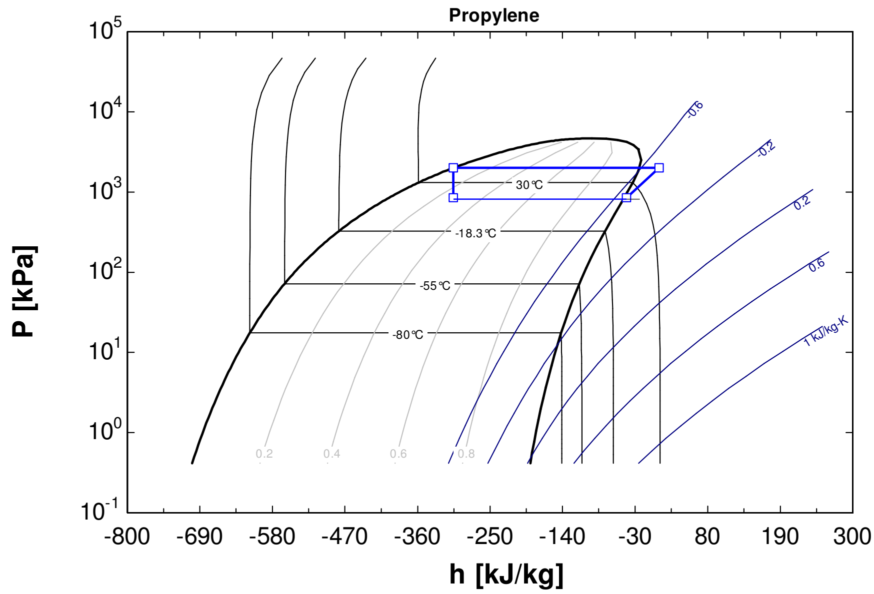

Figure 9. Propylene cycle for ambient air temperature of 24^{0}C

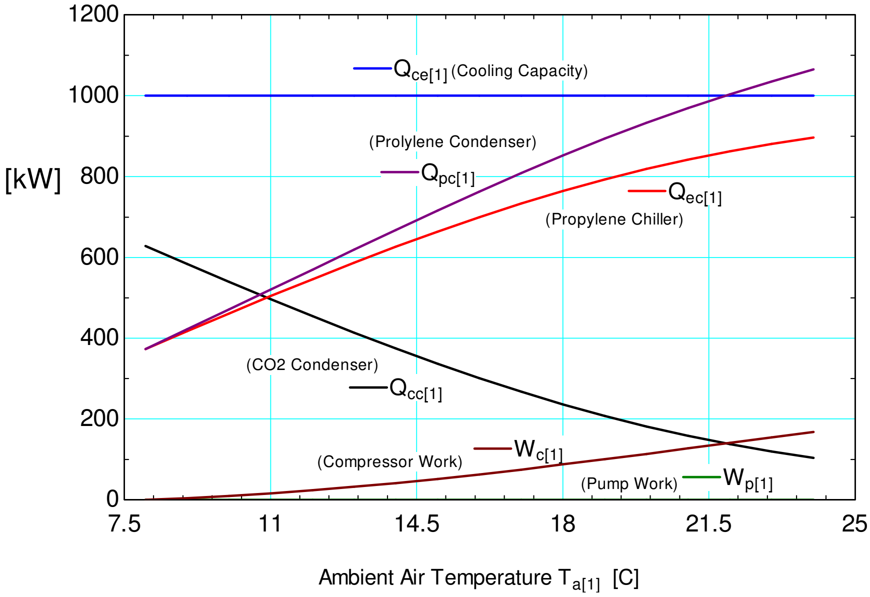

Figure 10. Energy Balance for Hybrid cooling

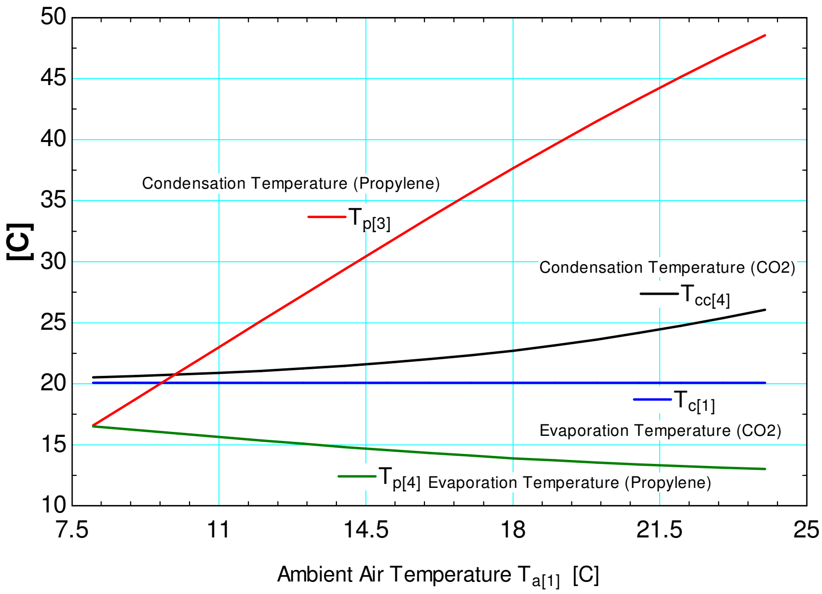

Figure 11. Evaporation and condensation temperatures for hybrid cooling

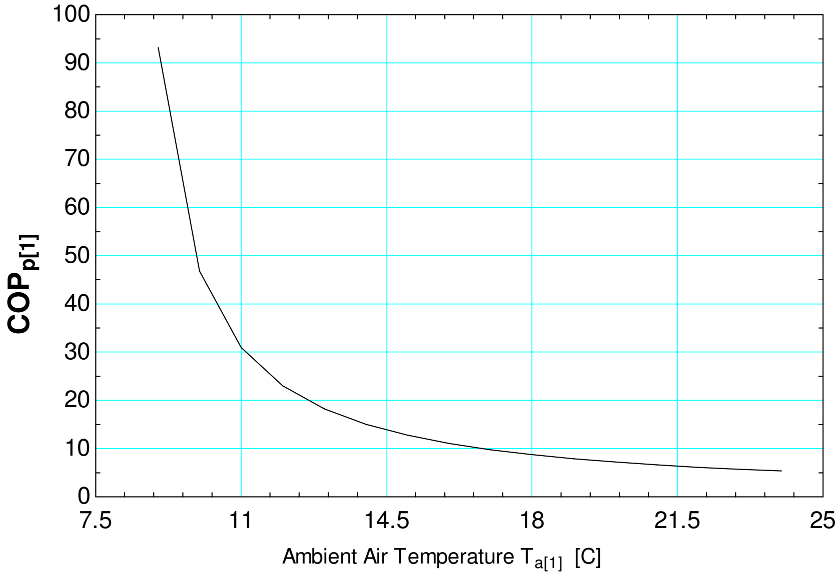

Figure 12. COP for Propylene cycle in hybrid cooling

It can be seen from figure 10 that for a constant cooling capacity the capacity of CO2 cycle to condense heat falls with ambient temperature and it is almost insignificant at 24^{0}C which has been set as maximum limit of operation for hybrid cycle. Also fraction of refrigerant mass flow of to CO_2 condenser falls. Figure 11 depicts evaporation and condensation temperatures for both CO_2 and propylene cycles. CO_2 evaporation temperature remains constant at 20.07 ^{0}C for this operation while condensation temperature varying with the changing ambient temperature. An inconsistency was observed in COP value for propylene cycle for operation at ambient temperature of 8^{0}C and has been omitted from figure 12 for variation COP with air temperature which otherwise is reasonable for entire range of temperatures.

4. Cooling with Propylene Condenser

As seen from last section, it is not feasible to operate cooling system in hybrid cycle mode for ambient temperatures greater than 24^{0}C. Following model which is suitable for operations at still higher temperatures is a simple cascade cycle where only propylene condenser operates as shown in figure 13.

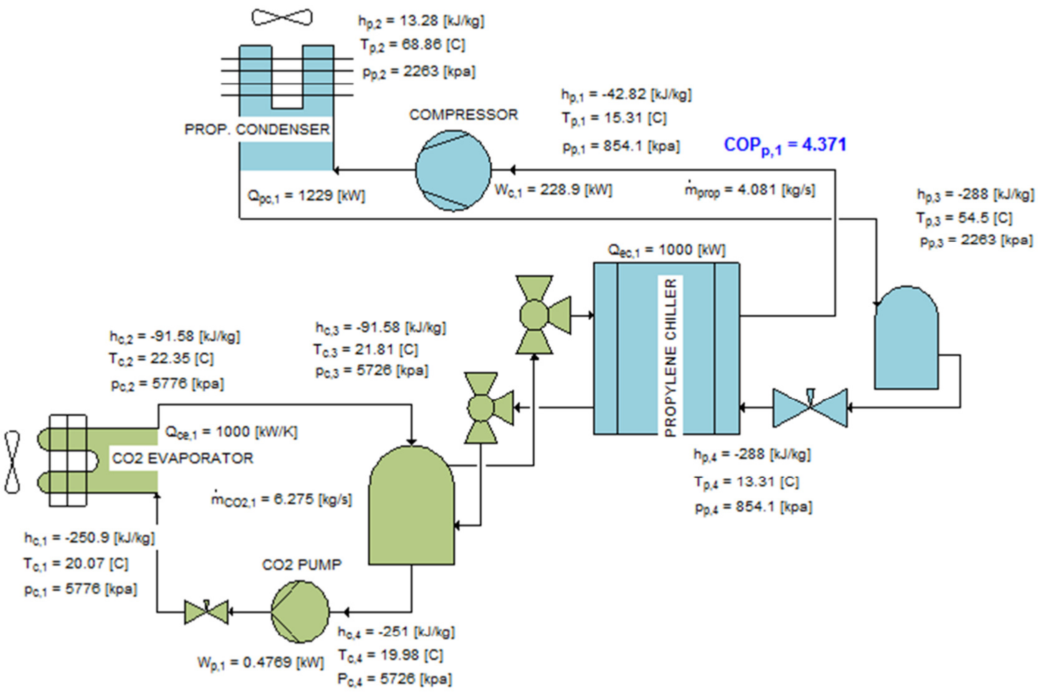

Figure 13. Model for cooling with the propylene condenser

The results for this model were plotted for a temperature range of 20 to 30^{0}C. Figure 14 shows the p-h diagram for the cycle. Propylene evaporation temperature is fixed by the model at 13.31^{0}C for entire temperature range as can be seen in figure 15. Same set of values for fixed flow rates and UA values were used as stated in earlier section for hybrid cycle. Figure 17 shows the variation of COP with ambient temperatures.

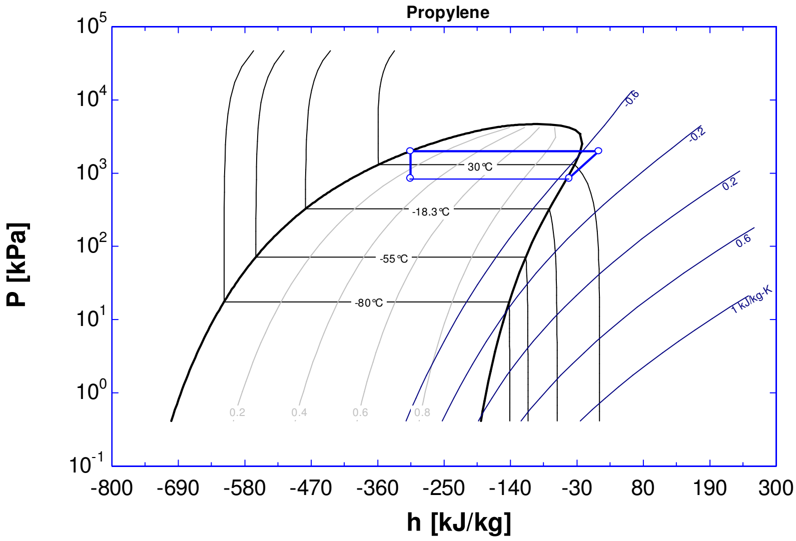

Figure 14. Propylene cycle for ambient air temperature at 30^{0}C

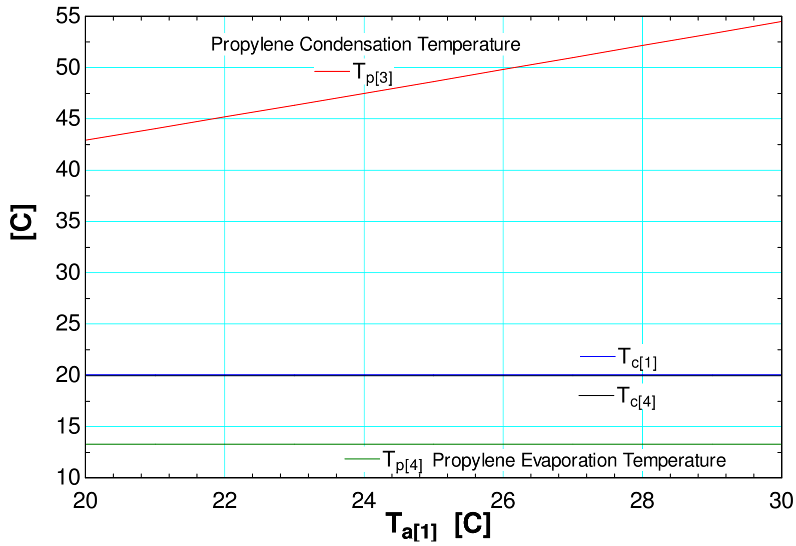

Figure 15. Evaporation and condensation temperatures for cooling with propylene condenser alone

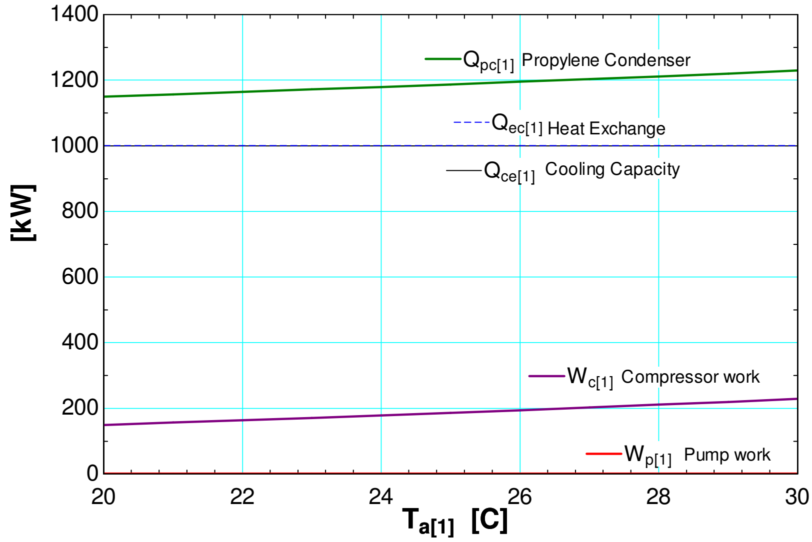

Figure 16. Energy Balance for cooling with propylene condenser alone

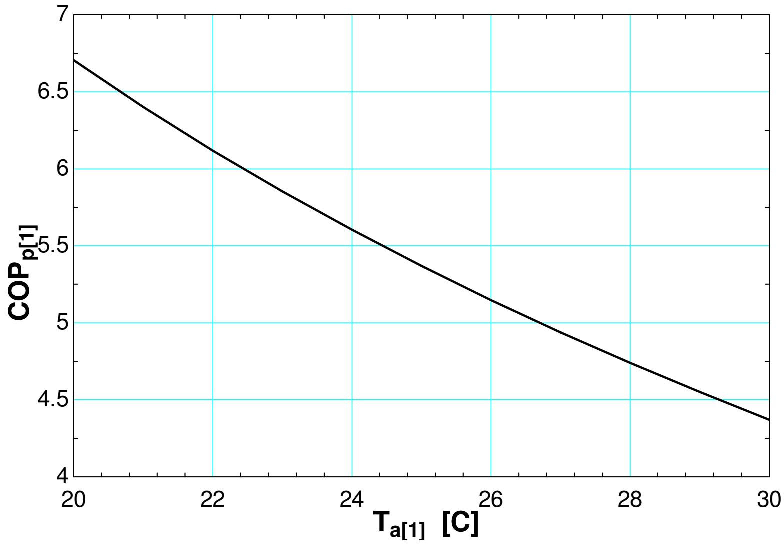

Figure 17. COP for propylene cycle for cooling with propylene condenser alone

5. Energy Savings and Conclusions

In these calculations, only energy input considered was from compressor and CO_2 pump while energy input from fans for blowing hot and ambient air was ignored. Total energy required to drive the cooling system is plotted in figure 18 for entire range of ambient temperature i.e. 1 to 30^0C. There is nearly a smooth transition at temperature of 24^0C where system switches from hybrid cooling mode to cooling with propylene condenser. Same can be said to be true for COP for propylene which has been plotted in figure 19.

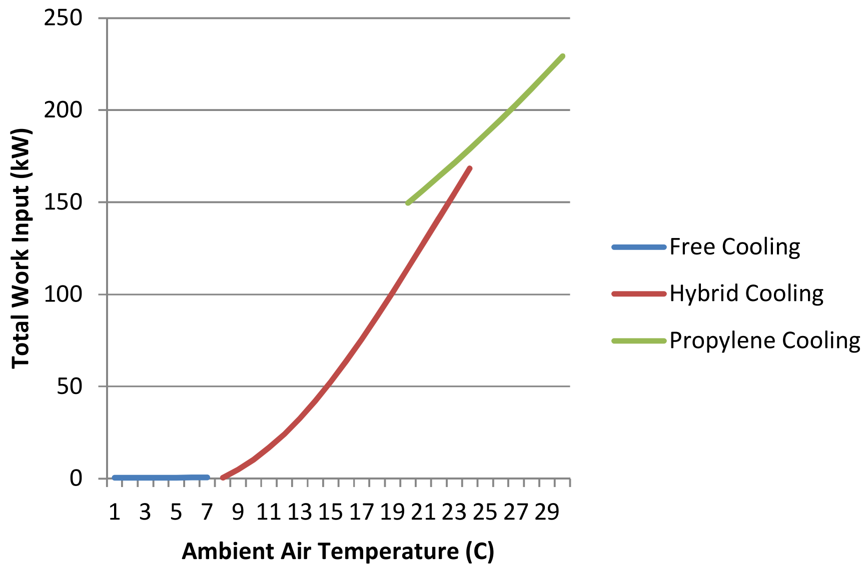

Figure 18. Energy Requirements for Cooling

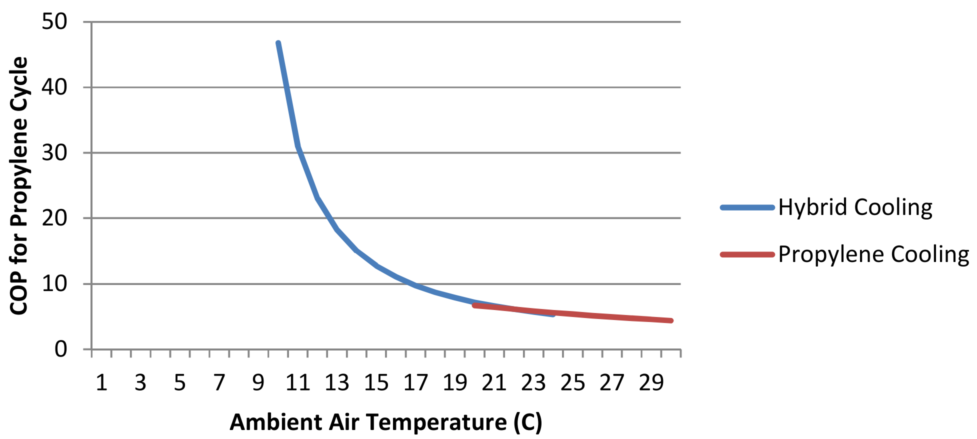

Figure 19. COP for Propylene Cycle

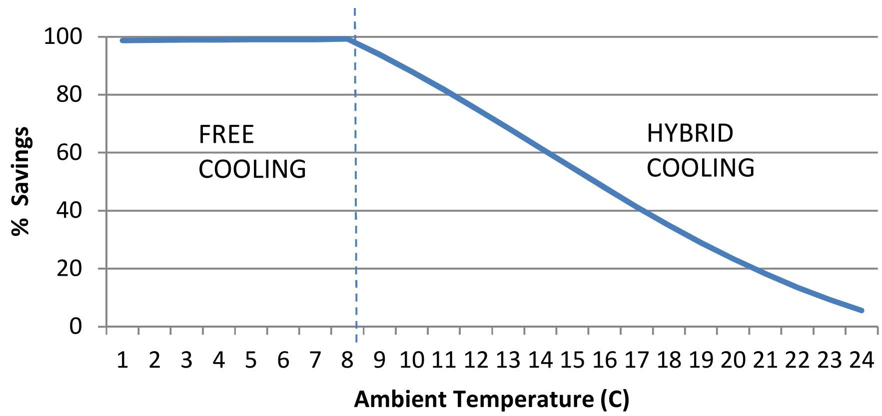

Figure 20. Energy savings (Percentage) at different temperatures

Figure 20 shows energy savings with variation in ambient temperature. The model with propylene condenser alone was used as reference for making energy saving calculations and it was run was entire range of ambient temperature. It can be seen that there is a significant level of energy savings can be achieved in free cooling region as well as hybrid cooling regions.