# 2 Energy saving strategies

## 2.1 Preamble

Various energy saving strategies were identified and considered to reduce the energy usage of deep level mine cooling systems. These systems comprise refrigeration machines, bulk air coolers (BACs), pre-cooling towers, condenser cooling towers and its auxiliaries. In order to understand the contribution and effect of each of the components, each of them were investigated in the following sections.

## 2.2 Evaporator flow control

Most mine refrigeration machines are operated at their fixed design evaporator flow while the variable demand for chilled water almost never reaches design demand [(13)]. When the chill dam is full, the water is often circulated back to the hot or pre-cool dams. Evaporator pump energy can therefore be reduced by controlling the evaporator flow with variable speed drives on the evaporator pumps to supply only the required water demand by keeping the chill dam level at a fixed set-point level below 100 %.

Often choke valves are used to calibrate the evaporator water flow to the design flow. By opening these valves and achieving design flow, by utilising variable speed drives (VSDs), a base energy saving will be achieved due to the cubic flow-power relation; where a small reduction in flow through a pipe network will result in a significant pump power reduction [(13)].

By reducing the evaporator flow according to the chill water demand and maintaining a fixed chill dam level below the overflow level, circulation of the water back into the hot or pre-cool dams is eliminated. This will result in an increase in the evaporator inlet water temperature and is advantageous because the chilled water temperature range increases. The increasing evaporator water inlet temperature causes a larger drive for heat transfer and increases the heat transfer effectiveness along with part-load operation and reduces the refrigeration machines' energy consumption [(14)]. This is realised due to higher suction pressures and therefore decreases the required work input.

Care should be taken when reducing the evaporator flow. If it is reduced too much it will result in laminar water flowing through the evaporator tubes which will substantially decrease the heat transfer coefficient of the heat exchanger and increase the build-up of fouling on the interior of the heat exchangers' tubes [(15)]. The flow should never reach 1m/s or lower. On the other end of the spectrum; the flow should not exceed 3m/s as this will cause erosion of the heat exchanger tubes, shortening the operational life [(16)].

## *2.3 Cooling tower control and efficiency*

Mine refrigeration systems often make use of pre-cooling towers to initially cool the warm process water before it goes through the refrigeration machines as well as condenser cooling towers to cool the condenser cooling water. Direct contact, also known as wet cooling towers are used where the water comes into direct contact with the ambient air allowing the water to approach the ambient web bulb (WB) temperature instead of only the dry bulb (DB) temperature [(17)]. This is due to the evaporative cooling effect of the direct contact between the water and air where the moisture content of the ambient air is less than the moisture content of saturated air at the warm water temperature. This causes some moisture to evaporate from the water into the air. The energy required for the evaporation is transferred from the water, resulting in an additional reduction in water temperature [(18)].

### 2.3.1 Fill material fouling

One of the most frequent reasons for cooling tower performance deterioration is fouling of the fill media on the interior of the tower, resulting in poor water distribution and decreased heat transfer. The function of the fill media is to increase the water heat transfer surface to allow for more heat to be extracted from the water. A comprehensive study on the cooling tower performance under increasing amounts of fouling has been done, which can be used to determine sensible maintenance intervals on cooling towers to ensure optimum tower benefit [(17)].

There are three commonly used types of fill material namely:

- ***Splash fill*** which generates more heat transfer area by breaking the water droplets into more smaller droplets. The total droplet surface area is the area through which heat transfer can take place.
- ***Film fill*** which is used to let the water form a film as it runs on the surface of the material usually being polyvinyl chloride (PVC) or polypropylene. The heat transfer area is made up of the total exposed area of the film of water.
- ***Low clog film fill*** which also creates a film of water that has less, but larger flutes.

Each of the types of fill mentioned above has its own advantages and disadvantages which are displayed in *Table 1*.

**Table 1: Design values of different types of fill** [19]

| | Splash fill | Film fill | Low clog film fill |
|---|---|---|---|
| Possible L/G ratio | 1.1 – 1.5 | 1.5 – 2.0 | 1.4 – 1.8 |
| Effective heat transfer area | 30 – 100 [$m^2/m^3$] | 150 [$m^2/m^3$] | 85 – 100 [$m^2/m^3$] |
| Fill height required | 5 – 10 [m] | 1.2 – 1.5 [m] | 1.5 – 1.8 [m] |
| Pumping head required | 9 – 12 [m] | 5 – 8 [m] | 6 – 9 [m] |
| Quantity of air required | High | Lowest | Low |

The fill media and the condition thereof represent a very important role in the overall performance of the cooling tower. The performance of pre-cooling towers can be increased by regular maintenance of the fill material and water distribution to ensure optimal heat transfer surface area [17].

### 2.3.2 Water and air flow

The liquid to gas (L/G) ratio represents the ratio of air to water mass flow rates through the cooling tower. Cooling towers have specific design specifications regarding the L/G ratio but is a function of the ambient air enthalpy and therefore has a dynamic optimal value as the ambient conditions changes [19].

When applying variable fan speed to cooling towers a substantial energy saving can be achieved by running the fan at partial loads during cooler climatic conditions. *Figure 3* shows how small the air flow reduction is when reducing the fan power. With a fan power reduction of 50 % relative to the full load, one can still maintain 80 % of the air flow relative to the full fan speed flow through a cooling tower by utilizing VSDs [20]. The difference between the two variable speed curves where eta is constant and varied is a representation of the difference between constant and varied overall fan efficiency.

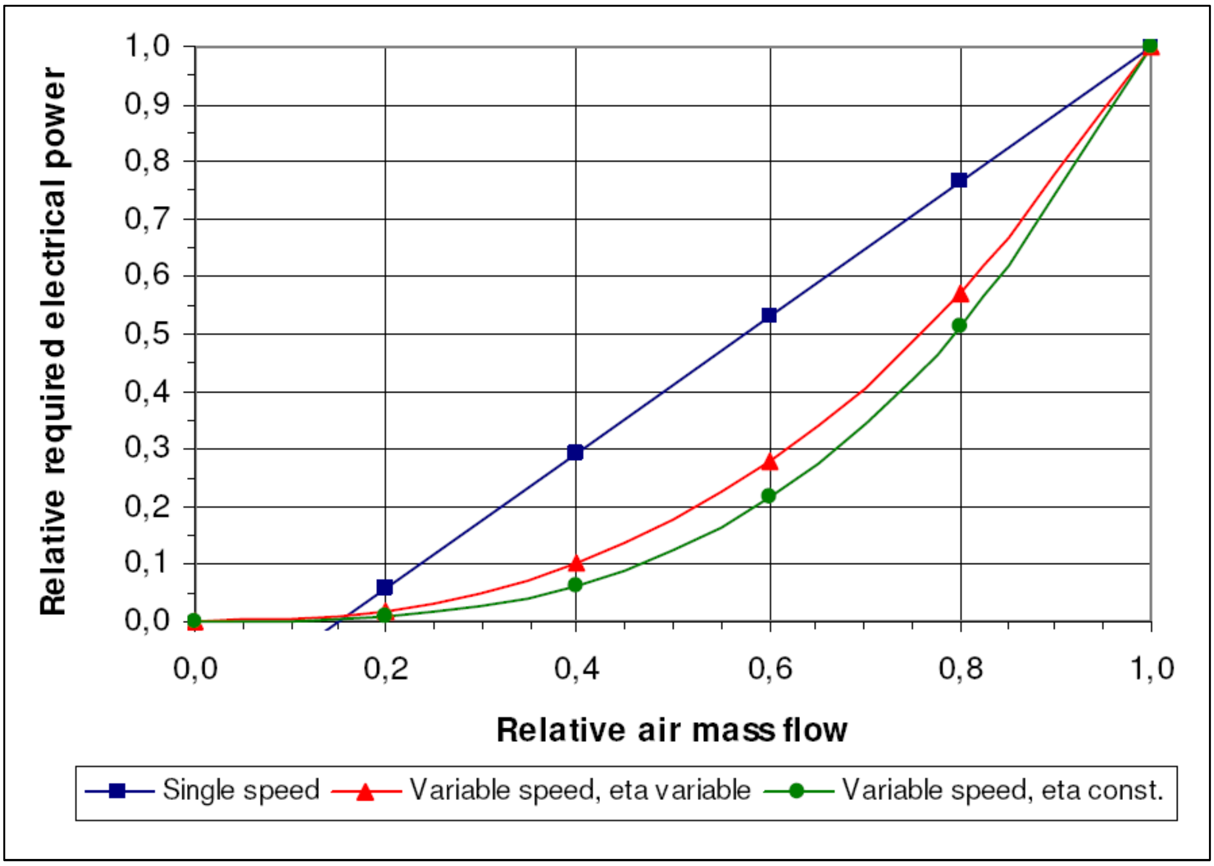


**Figure 3: Cooling tower electrical power as a function of variable air flow [20]**

When applying variable water flow through the cooling tower it also changes the L/G ratio. *Figure 4* shows the non-linear relation between the water outlet temperature and the change in the L/G ratio. The outlet water temperature will decrease as the water flow rate is decreased without changing the air flow rate and vice versa [21].

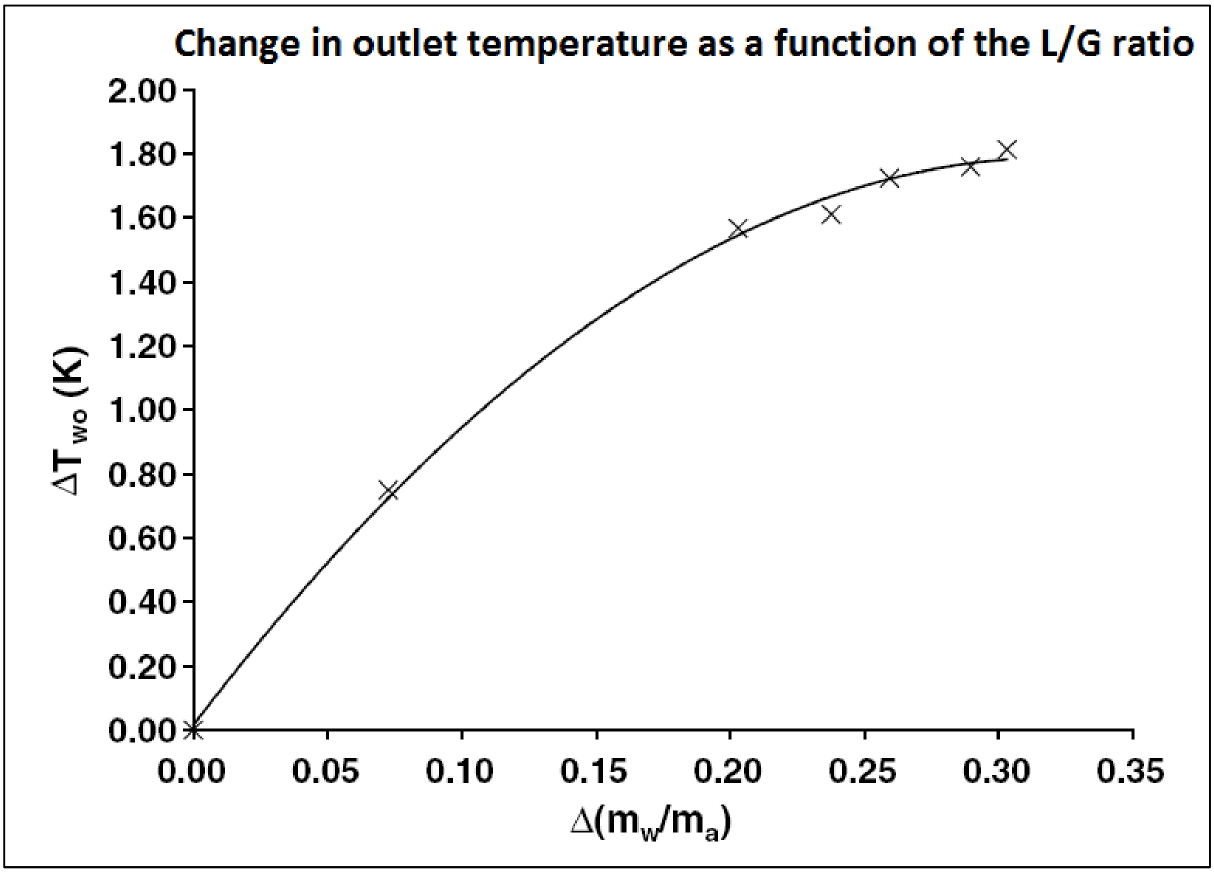


**Figure 4: Cooling tower water outlet temperature as a function of the L/G ratio** [21]

### 2.3.3 Cooling tower performance

Efficient pre-cooling towers operate at water/air approach temperatures of between 2 ºC to 3 ºC, meaning that the water outlet temperature decreases to between 2 ºC to 3 ºC above the ambient air WB temperature with an inlet/outlet water temperature range of 6 ºC to 8 ºC [19].

A well maintained cooling tower operates, during design conditions, at a coefficient of performance (COP) of approximately 30 while the COP of an efficient refrigeration plant is only in the range of 6 [22]. For this reason, it is preferable to have the cooling tower perform as much cooling to the water as possible before it goes through the refrigeration machine. This can be achieved via the application of appropriate water and air flow control to the cooling tower.

## 2.4 Bulk air cooler flow control

Surface BACs are used to cool down and dehumidify surface ambient air to an acceptable temperature and humidity to be used underground. After cooling, the air is circulated through the mine [(23), (17)]. The BAC typically cools the ambient air from approximately 22 ºC WB to approximately 8 ºC WB [(24), (25)]. All the cooling tower performance related items such as fill material fouling, water and air flow, discussed in Section 2.3 also applies to BACs, as it is also a counter flow wet cooling tower.

The BACs are designed to cool ambient air at approximately 22 ºC WB to approximately 8 ºC WB; however, the surface ambient air is usually below this design WB temperature of 22 ºC. Consequently, cooling demand control can be applied by reducing the chilled water flow through the BAC resulting in an energy saving on the refrigeration plant due to the reduction in cooling demand during lower WB ambient air periods. In this way the cooling demand on the refrigeration machine will gradually decrease as the season changes from summer to winter instead of only a step change when the BACs are switched off manually, after the climate has already cooled down substantially.

## 2.5 Condenser water and cooling tower air flow control

Most of the compressor energy used by a refrigeration machine's compressor is used to move the refrigerant vapour from the low pressure in the evaporator to the high pressure in the condenser. As the pressure differential increases the load on the compressor motor to enable it to move the refrigerant. By lowering the condenser cooling temperature the pressure differential also decreases and results in a reduction in the load on the compressor and subsequently its electrical motor's power [(13)]. This is known as Condenser reset.

By varying the condenser cooling water flow rate and condenser cooling tower fan speeds, the condenser cooling temperature can be controlled and lowered as the demand for heat rejection changes along with the load variance of the refrigeration machine. Reducing and controlling the fan speed of the condenser cooling tower can also be applied to control the outlet water temperature of the condenser cooling tower, as the ambient conditions change, to obtain the desired temperature that corresponds to a specific condenser water flow rate and refrigeration machine load [(26)].

The plot in *Figure 5* suggests that there exists an optimal point where the minimum overall electrical energy is consumed by an entire plant including the refrigeration machine, condenser water pumps and condenser cooling tower fans [14].

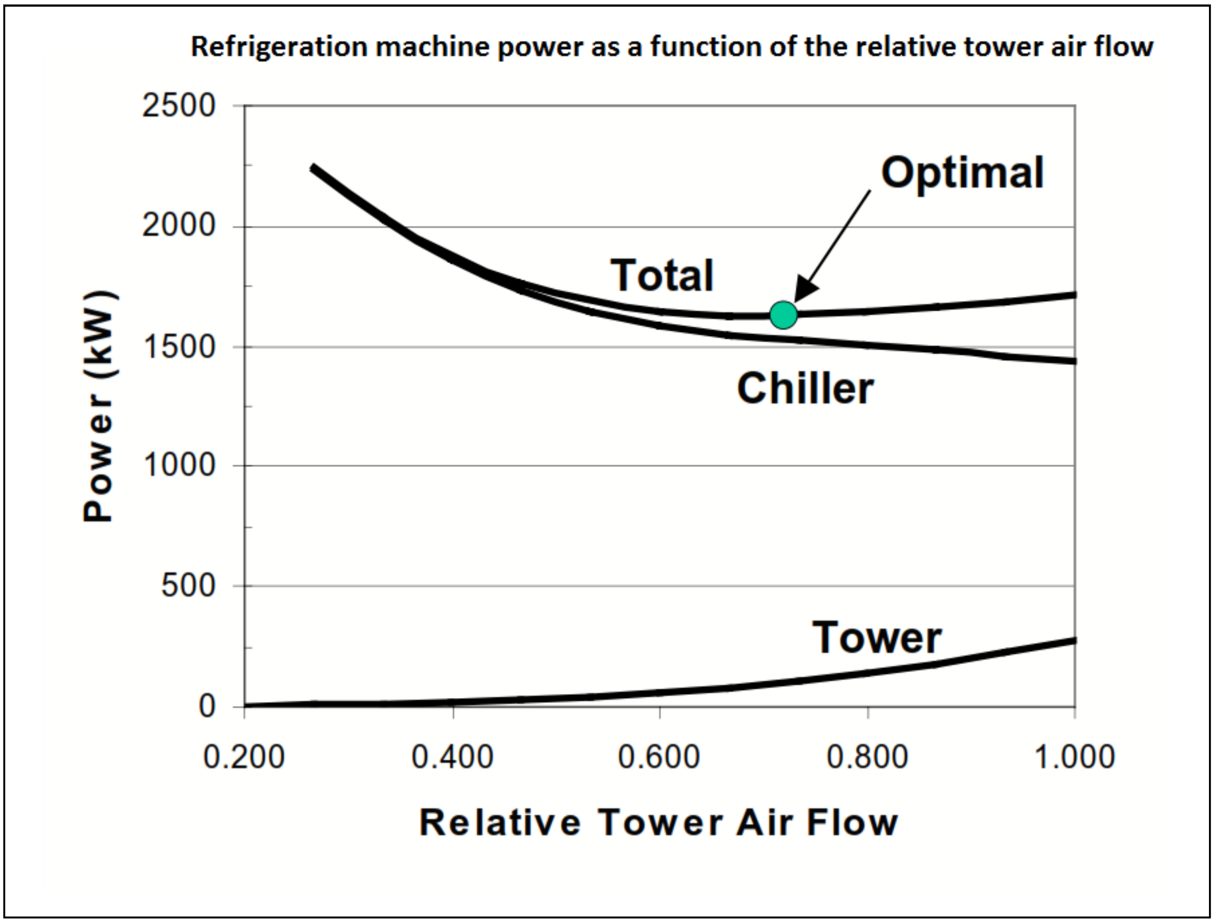


**Figure 5: Condenser cooling tower air flow optimal point [14]**

Typical system power as a function of the condenser water flow rate as well as the cooling tower fan speed is shown in *Figure 6* to *Figure 8*. In *Figure 6*, it is apparent that for fan speeds above 60 % the minimum system power corresponds to a condenser water flow of 90 % for a 70 % load and ambient air conditions of 21.1 ºC (70 ºF) WB [27].

In *Figure 7*, the minimum system power is achieved at 90 % condenser water flow for fan speeds above 60 % with the system load being 70 % and ambient air conditions of 10 ºC (50 ºF) WB.

In *Figure 8*, the load has been reduced to 30 % with the same ambient air conditions as in *Figure 7* of 10 ºC (50 ºF) WB. In this case, the minimum system power is obtained between

70 % to 80 % condenser water flow rates. It is noteworthy that at these conditions, the influence of the fan speed is not as large as was found in the previous two cases.

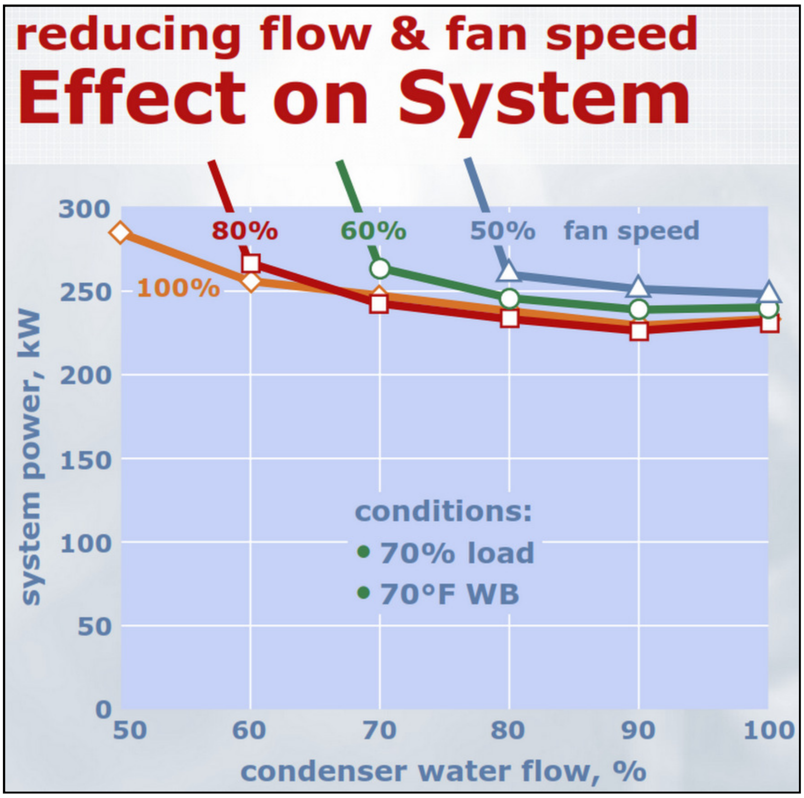


Figure 6: Reducing condenser flow and fan speed effect on system, case 1 [27]

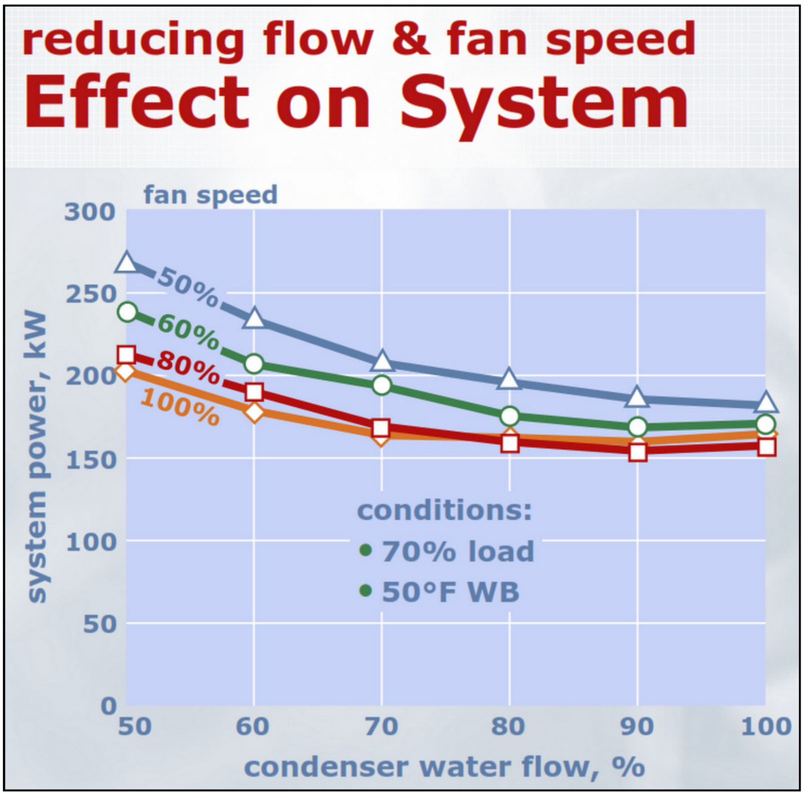


Figure 7: Reducing condenser flow and fan speed effect on system, case 2 [27]

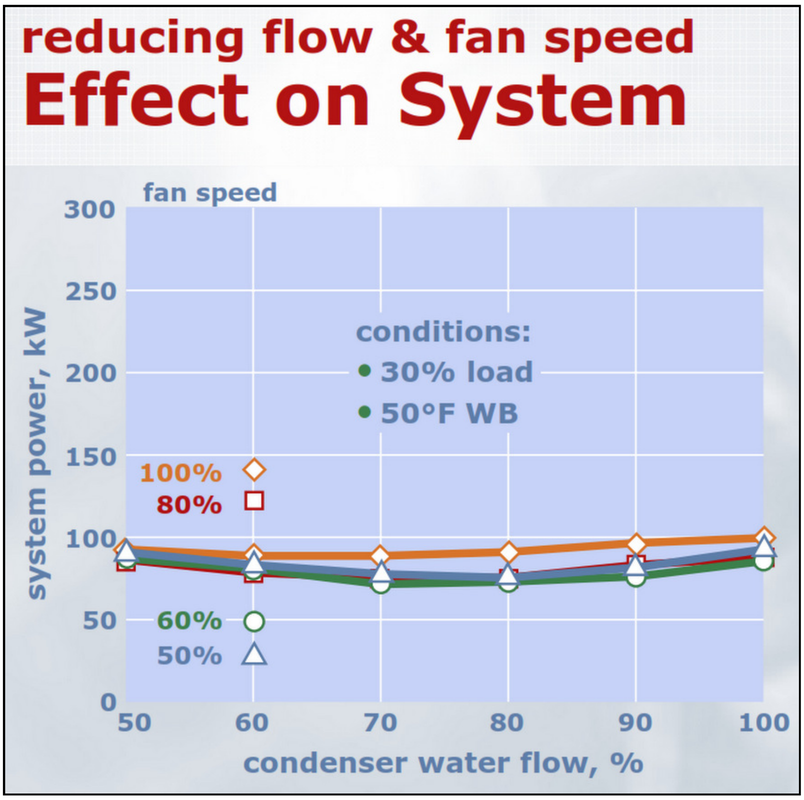


Figure 8: Reducing condenser flow and fan speed effect on system, case 3 [27]

From the results obtained it can be concluded, that a dynamic optimal point for the overall system power always exist, through combinations of varying the condenser water and condenser cooling tower air flow rates.

## 2.6 Simulation

A method to accurately obtain the results in the event of applying more than one of the identified strategies or any combination thereof to a cooling system would be through simulation. Simulation will be the only way in which the various effects of each strategy will be captured as its change affects the system as a whole. The change of any given parameter of one part of the system has a dynamic effect further downstream and with such a multi-variable system, it would be impossible to determine the effect by means of first principle calculations on each part separately.

## 2.7 Conclusion

Each strategy has its own potential savings magnitude and will vary for each unique system. Consequently, each system will have to be uniquely investigated to determine which of the strategies are relevant to the specific case.

After the relevant strategies are identified, their contribution to energy saving of the system will have to be determined. For this purpose a simulation model, as discussed in the next chapter, will be used.