Cairo University
Faculty of Engineering
Mech. Power Department

دبلوم تطبيقات التحكم الأوتوماتيكى
فى نظم القوى الميكانيكية

# MEP 599 Diploma Design Project- Summer Term 2015

## Chilled Water Piping Systems for HVAC Units (Design and Calculations)

by

**Eng. Ahmed El-Sayed Ibrahim Gad and Eng. Abd El-Fatah Omar Osman Ahmed**

Supervised by

**Dr. Mohsen Sayed Soliman , ACC Manager and Dr. Amro Abdel Raouf, ACC Vice Manager**

Mechanical Power Engineering Department

***Abstract:*** **This project provides description & case study of common chilled water system types used for HVAC units from the basic constant flow to all variable systems along with the advantages and Limitations; Providing efficient distribution system using variable flow that tracks the variable loads.**

Chilled water pumping systems are divided into three categories:

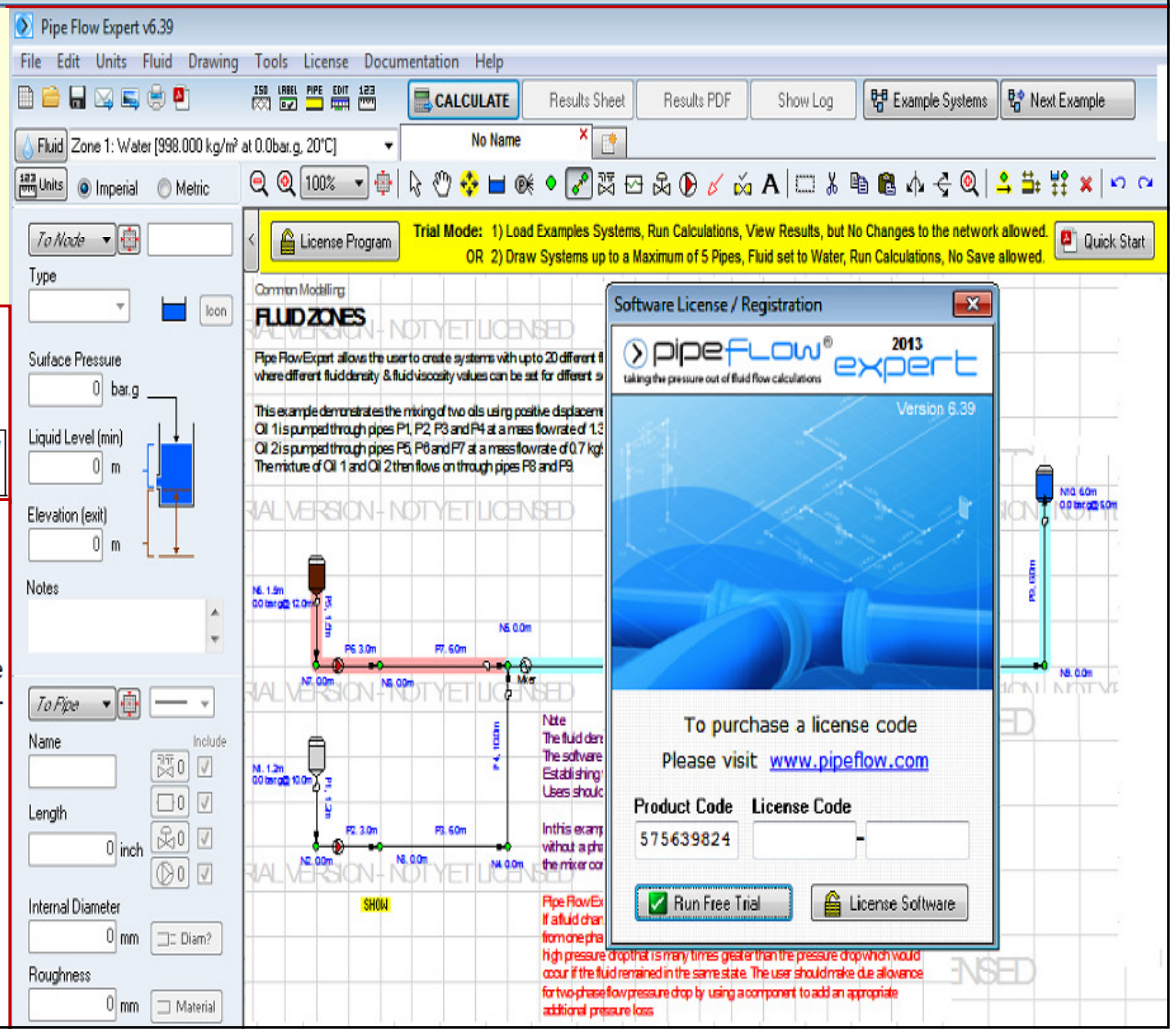
**Chilled Water Piping System**

- **a. Constant Volume Chilled Water System**
- **b. Primary/ Secondary Chilled Water System**
- **c. Variable Primary Flow Chilled Water System**

## Objective of the study

The objective of the study includes major objective and minor objective that we can describe the major objective is the loop control for temperature, and piping head losses (contains pipe and fitting losses). Here is a brief detail how and what will accomplished.

1. **Piping head losses:** this stage will be accomplished to control the demand flow rate inside pipe by selecting pumps and determining their arrangement to overcome major and minor losses of the piping.
2. The selection of the best arrangement pumps is depend on a lot of things such as **energy consumption**, solving ΔT, maintenance, etc.
3. **Loop control:** this stage will be done to control temperature difference which is the chiller task where the evaporator controls the outlet temperature to AHU, flow rate control will be achieved by valves where we may select the suitable valve size according to the following equation $G=C_v(\Delta P)^{1/2}$ also cooling control by face and bypass control will be done in this stage.



# Project case study basic concepts

1- In chilled water systems, water is distributed throughout the entire hydraulic network

**The chilled water flow rate** required for a given **heat load** is determined as follows:

$$CWFR = \frac{HL}{\rho \times 60(mm/hr) \times SG \times SH \times \Delta T}$$

*Where*

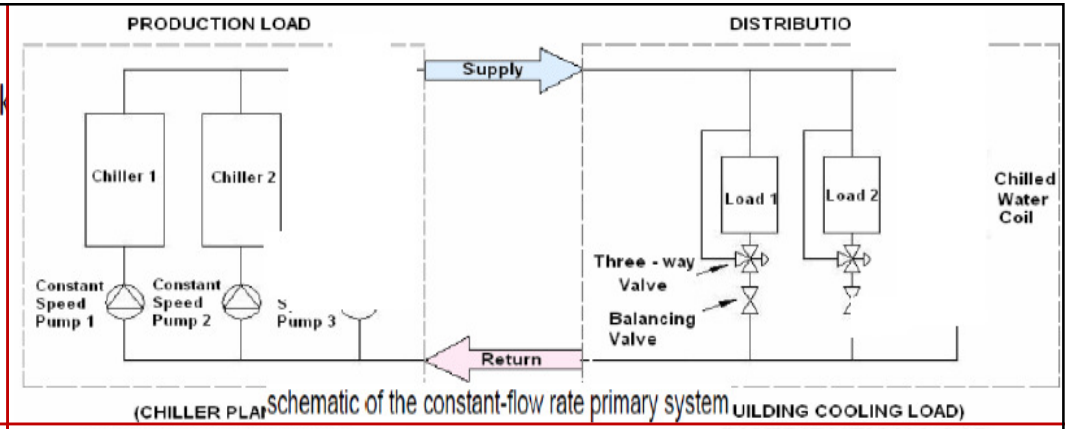
**CWFR**: *Chilled water flow rate (gal/min)*

**HL**: *Heat load (BTU/hr).....or chiller capacity*

$\rho$: Liquid density (water density = 8.34 lb/gal) **SG**: Liquid specific gravity (water specific gravity = 1)

**SH**: Liquid specific heat (water specific heat = 1 BTU/lb-°F)

**ΔT**: Chilled Water temperature differential [i.e. T return water - T supply water] in $^{0}F$

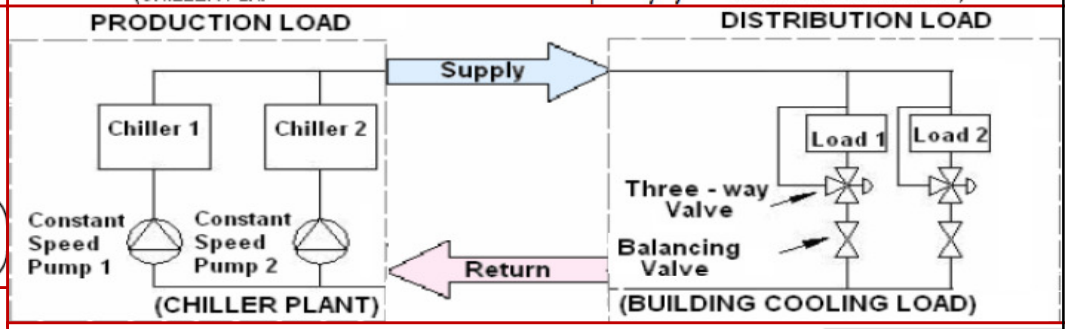



schematic of the constant-flow rate primary system

## Pump Affinity Laws:

The affinity laws are rules that govern the performance of a pump under varying conditions of flow and pressure. The laws can be roughly stated as follows:

- Flow varies with rotating speed
- Head varies with the square of the rotating speed
- Brake horsepower varies as the cube of the rotating speed




## Piping Analysis Technique

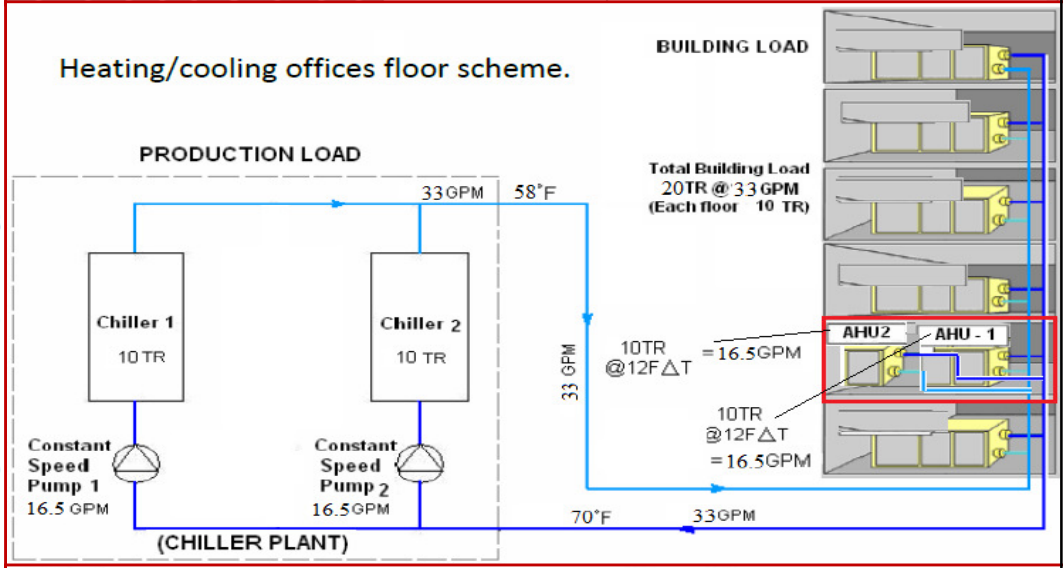
In this project we used **Pipe Flow Expert software application** for **design** and **analyzing** complex pipe networks where the flows and pressures must be balanced to solve the system.

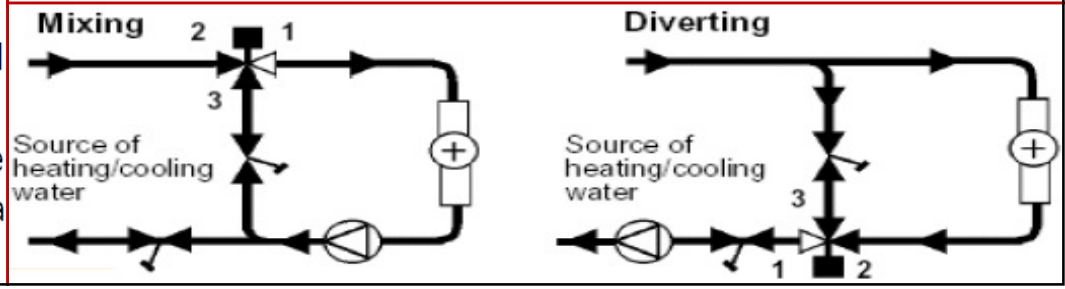
Friction Factors are calculated using the **Colebrook-White equation**.

Friction Loss is calculated using the **Darcy-Weisbach method**, which provides accurate results for non-compressible fluids, including most process fluids. This method also provides satisfactory results of reasonable accuracy for compressible fluids (gases) when the pressure drop in the system is less than 10% of the pressure at the compressible fluid entry points. If the calculated pressure drop in the system is greater than 10% but less than 40% of the pressure at the compressible fluid entry points then the **Darcy-Weisbach** equation will give reasonable accuracy provided that the calculations are repeated using the average density of the fluid in the pipeline system.

**Flow and Pressure Loss Calculations** produced by the Pipe Flow Expert software can be verified by comparison against published results from a number of well known sources.

The information in this document provides a general description of a published problem, the Reference Source, the Published Results Data, the **Pipe Flow Expert Results Data** and a commentary on the results obtained.



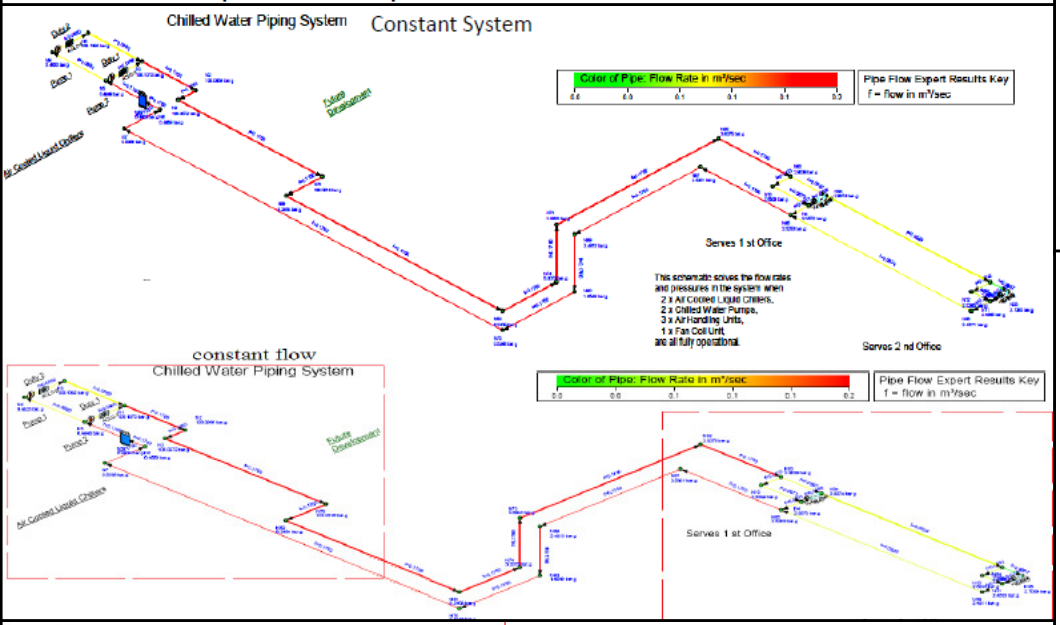



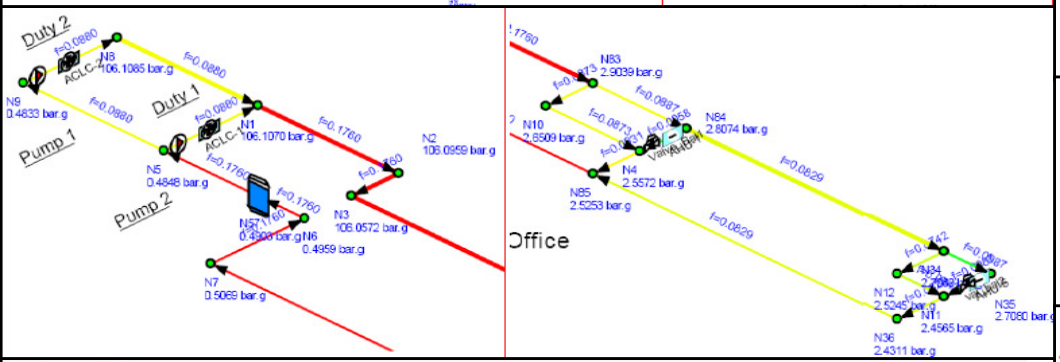
# Piping Circuit Analysis for Constant Chilled Water Piping System

There is other schematic drawn by using **Pipe Flow Expert**; these schematics help us to make the idea of the project closer where the constructors will use them easily if they needed to construct them later.

In our Piping study we divided the Total Cooling Load described previously in to 3 periodic times: a) Morning Operation Condition: from 8 am to 11 am

- **Cooling Loads:** 0.25 of Total Calculated BTU for first Office &0.375 of Total Calculated BTU for second Office
- **Flow rate for first Office circuit equals 0.0058 $m^3/s$ & Flow rate for first Office circuit equals 0.0087 $m^3/s$**




## Pump Data

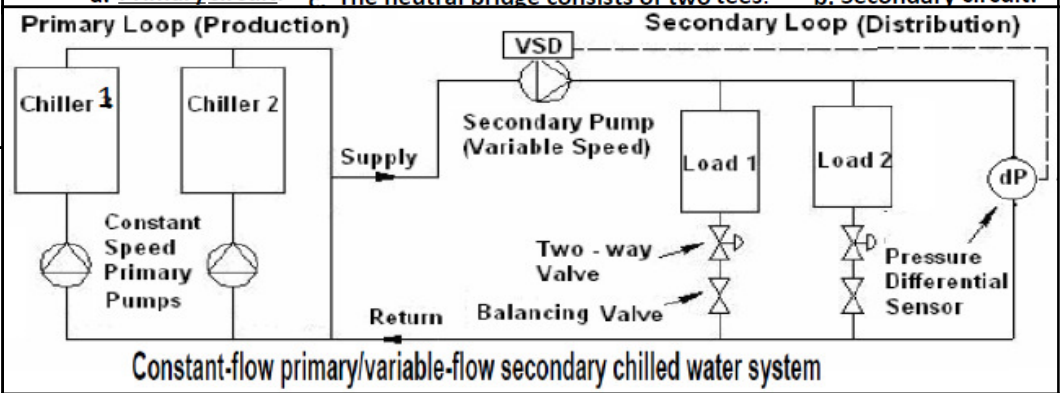
| Pipe Id | Pipe Name | Pump Name | Speed rpm | Pref. Op From m³/sec | Pref. Op To m³/sec | Flow In/Out m³/sec | Velocity m/sec | Suction Pressure bar.g | Discharge Pressure bar.g | Pump Head (+) m.hd Fluid | Pump NPSHr m.hd (absolute) | Pump NPSHa m.hd (absolute) | Pump Efficiency Percentage | Pump Power Kilowatts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | P4 | Pump | Set Flow Rate | | | 0.0880 | 4.721 | 0.4848 | 108.9047 | 1105.575 | Not known | 15.151 | Not known | Not Known |
| 7 | P7 | Pump | Set Flow Rate | | | 0.0880 | 4.721 | 0.4833 | 108.9061 | 1105.605 | Not known | 15.136 | Not known | Not Known |

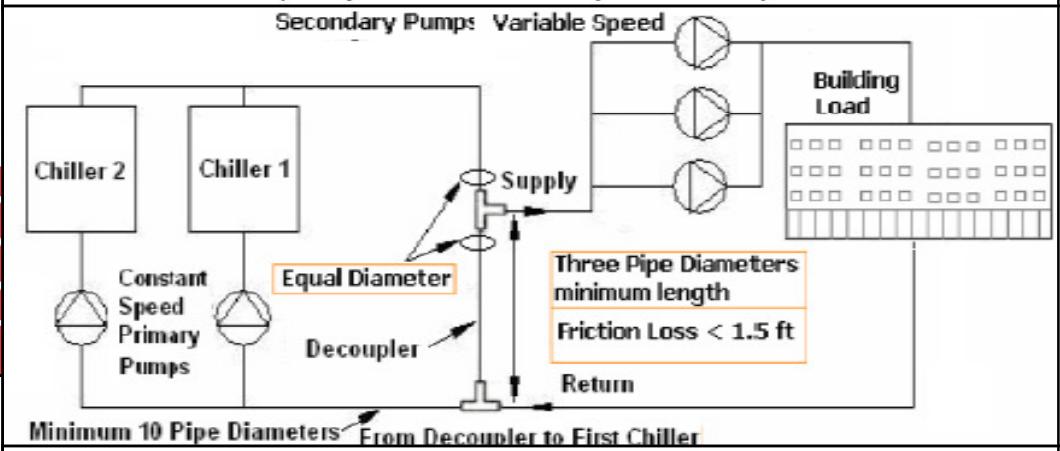
# Primary/Secondary Chilled Water Systems

*ASHRAE/IES Standard 90.1- 1989* - Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings requires "**All HVAC systems having a total pump system power exceeding 10 hp must be capable to flow at 50 % of design value or less.**"

This standard highly recommends use of **primary/secondary system** for large complexes. A **primary- secondary pumping scheme** divides the chilled water system into **two** distinct circuits (loops) ***[that are hydraulically separated by a neutral bridge (de-coupler)]***:

a. Primary circuit. c. The neutral bridge consists of two tees. b. Secondary circuit.



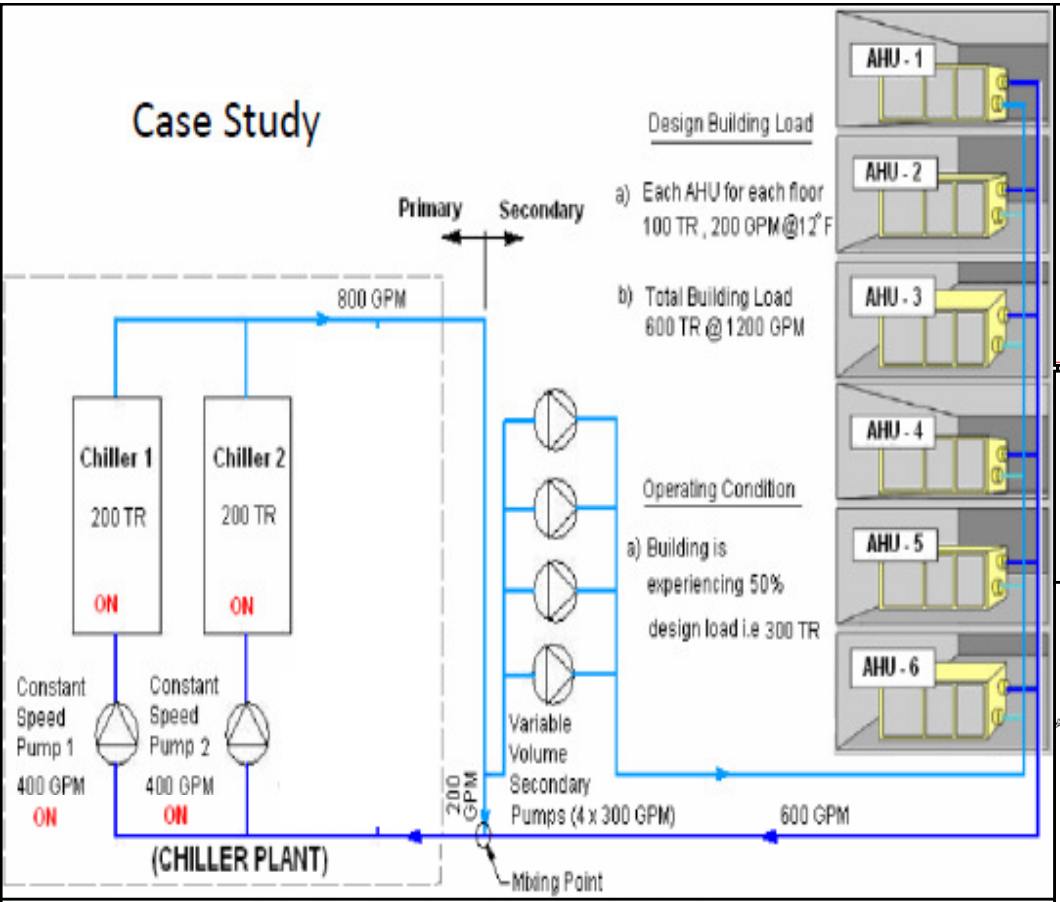



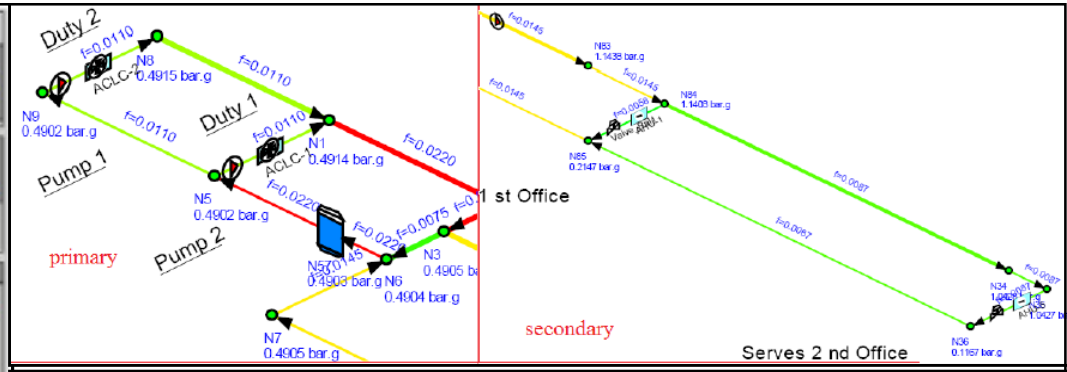

## Primary circuit:

Primary circuit is the place where chilled water is produced and its principal components are the **chiller** and **pumps**. The primary pumps are typically **constant volume**, **low head pumps** intended to **provide a constant flow** through the evaporator of the chiller. These are usually placed in **tandem with each chiller** though can also be arranged in common header. **Water flows** through the chiller primary loop at a **constant rate.**

## Secondary circuit:

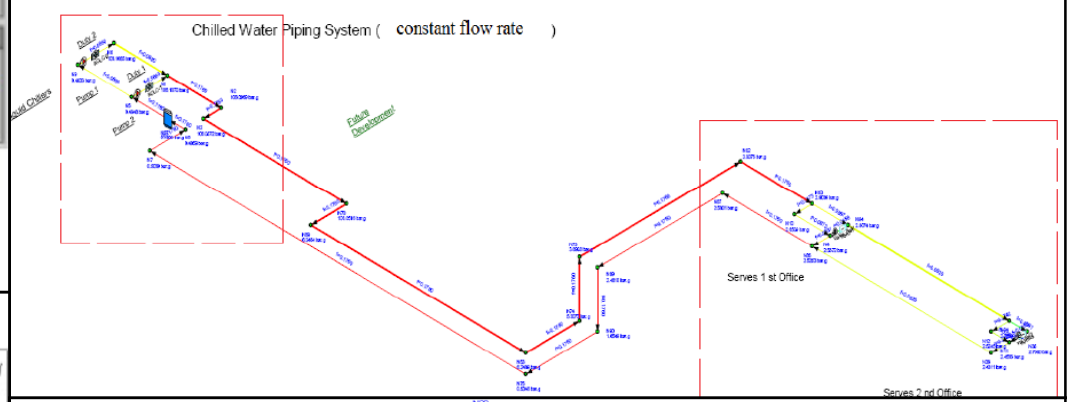
The secondary circuit is responsible for the distribution of the chilled water to the **terminal units**. Among the components of secondary circuits are **pumps**, terminal units such as **fan-coils** and **air handling units** (AHU) and **control valves**. The secondary pumps can be **constant speed or variable speed** and are sized to move **flow rate** and **head** intended to overcome **pressure drop** of secondary circuit only

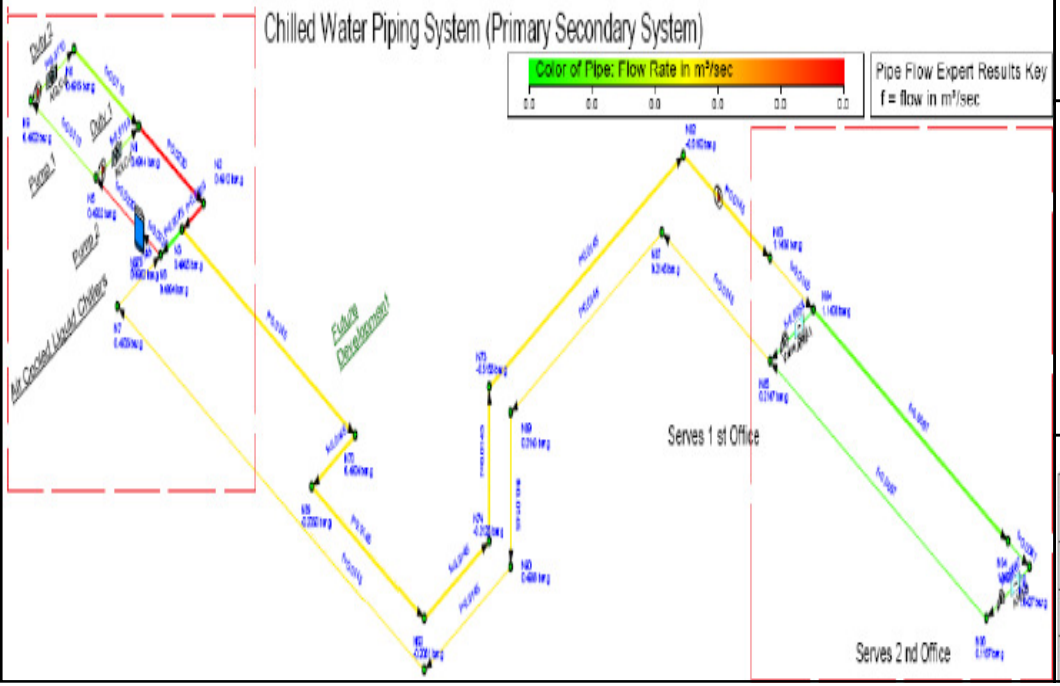


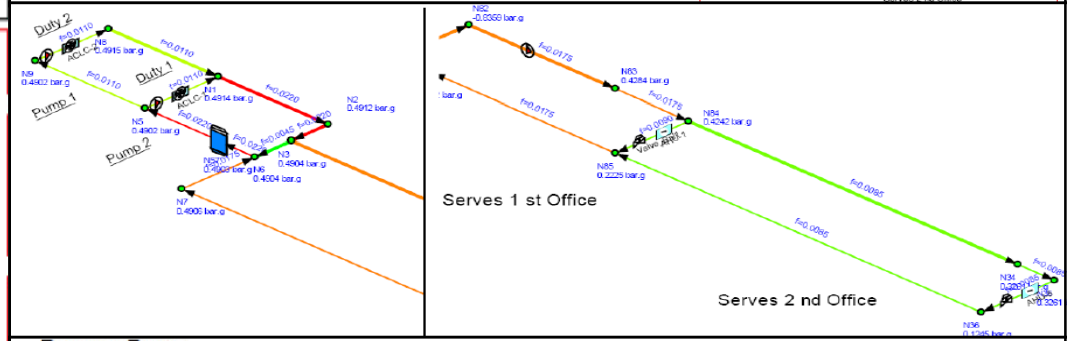




## Pump Data

| Pipe Id | Pipe Name | Pump Name | Speed rpm | Pref. Op From m³/sec | Pref. Op To m³/sec | Flow In/Out m³/sec | Velocity m/sec | Suction Pressure bar.g | Discharge Pressure bar.g | Pump Head (+) m.hd Fluid | Pump NPSHr m.hd (absolute) | Pump NPSHa m.hd (absolute) | Pump Efficiency Percentage | Pump Power Kilowatts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | P4 | Pump | Set Flow Rate | | | 0.0110 | 0.590 | 0.4902 | 0.5728 | 0.842 | Not known | 15.206 | Not known | Not Known |
| 7 | P7 | Pump | Set Flow Rate | | | 0.0110 | 0.590 | 0.4902 | 0.5728 | 0.842 | Not known | 15.206 | Not known | Not Known |
| 99 | P99 | Pump | Fixed Head Rise | | | 0.0145 | 1.765 | -0.5189 | 1.1482 | 17.000 | Not known | 4.915 | Not known | Not Known |



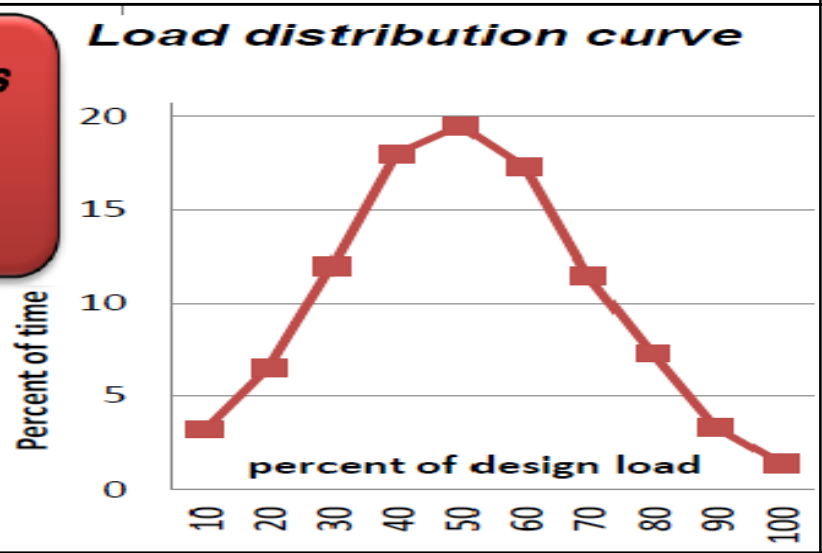

## Pump Data

| Pipe Id | Pipe Name | Pump Name | Speed rpm | Pref. Op From m³/sec | Pref. Op To m³/sec | Flow In/Out m³/sec | Velocity m/sec | Suction Pressure bar.g | Discharge Pressure bar.g | Pump Head (+) m.hd Fluid | Pump NPSHr m.hd (absolute) | Pump NPSHa m.hd (absolute) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | P4 | Pump | Set Flow Rate | | | 0.0110 | 0.590 | 0.4902 | 0.5728 | 0.842 | Not known | 15.206 |
| 7 | P7 | Pump | Set Flow Rate | | | 0.0110 | 0.590 | 0.4902 | 0.5728 | 0.842 | Not known | 15.206 |
| 99 | P99 | Pump | Fixed Head Rise | | | 0.0145 | 1.765 | -0.5189 | 1.1482 | 17.000 | Not known | 4.915 |

| Design load percent | Ton | GPM system | Secondary Pump head | Pump No. | Primary pump Kw | Secondary pump Kw | Total pump kw | on cheller Kw | Total KW | percent of season | Seasonal hours | Seasonal Kwh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 2 | 3.3 | 11.4 | 1 | 0.1922 | 1E-08 | 0.1922 | 0.00016 | 0.192 | 3.2 | 105.12 | 20.219022 |
| 20 | 4 | 6.6 | 12.9 | 1 | 0.1922 | 3E-08 | 0.1922 | 0.00028 | 0.192 | 6.5 | 213.525 | 41.09643 |
| 30 | 6 | 9.9 | 16.026 | 1 | 0.1922 | 5E-08 | 0.1922 | 0.00043 | 0.193 | 12 | 394.2 | 75.928579 |
| 40 | 8 | 13.2 | 19.758 | 1 | 0.1922 | 8E-08 | 0.1922 | 0.0006 | 0.193 | 18 | 591.3 | 113.99157 |
| 50 | 10 | 16.5 | 24.3858 | 1 | 0.1922 | 1E-07 | 0.1922 | 0.00084 | 0.193 | 19.5 | 640.575 | 123.64333 |
| 60 | 12 | 19.8 | 29.8716 | 2 | 0.3844 | 2E-07 | 0.3844 | 0.00085 | 0.385 | 17.3 | 568.305 | 218.9213 |
| 70 | 14 | 23.1 | 38.142 | 2 | 0.3844 | 2E-07 | 0.3844 | 0.001 | 0.385 | 11.5 | 377.775 | 145.57952 |
| 80 | 16 | 26.4 | 43.1142 | 2 | 0.3844 | 3E-07 | 0.3844 | 0.00114 | 0.386 | 7.3 | 239.805 | 92.445493 |
| 90 | 18 | 29.7 | 51.2574 | 2 | 0.3844 | 4E-07 | 0.3844 | 0.00128 | 0.386 | 3.3 | 108.405 | 41.805869 |
| 100 | 20 | 33 | 60 | 2 | 0.3844 | 5E-07 | 0.3844 | 0.00142 | 0.386 | 1.4 | 45.99 | 17.742375 |
| Σ | | | | | | | | | 2.891 | 100 | 3285 | 891.37348 |

| drive Eff. | pump Eff | Motor Eff. |
|---|---|---|
| 76 | 71 | 88 |
| 80 | 80 | 91 |
| 84 | 79 | 92 |
| 88 | 76 | 93 |
| 91 | 68 | 94 |
| 89 | 80 | 93 |
| 92 | 80 | 94 |
| 93 | 80 | 94 |
| 94 | 80 | 94 |
| 94 | 80 | 93 |

secondary pump characteristics according to manufacturer




## Energy Analysis Conclusion

Energy used is determined by the same two equations at various load conditions where it calculated at 10% load intervals by equation one and two. The annual energy usage for the variable flow rate system is 891.373 Kwh/yr as clearly written in above table. This is 29.44% of constant flow rate system's pumping energy usage. This is annual saving money and power.

## Conclusion

Obviously, the variable flow rate system offers significant power savings. The above example proved a typical chilled water plant results about 70% pumping energy savings

The cost effectiveness of the system conversions will depend upon the upcoming factors:

1. The number of operating season hours. 2. Load variation from mini to maximum flow.
3. Electrical energy cost.

There are numerous variations to the variable flow rate system where each chilled water plant should be retrofitted (modified) to the most suitable system.