ELECTRICAL CONSUMPTION BALANCE OF CHILLERS COOLING LOAD

BY NASER SH F ALAJMI

Abstract— Air condition systems is the largest consumer of electrical energy in industrial factories and commercial buildings. It account over 60% of electrical power use in buildings. In chilled water plant systems the chiller and other components electrical load fluctuates, this lead that all chillers change their capacity to provide the required load. None of the chillers are in a base load / trim sequence strategy . Chiller plant air condition system optimization becomes a priority efficiency upgrade , this reduces electrical energy usage and costs by 30% and improves plant reliability by running equipments more efficiently .In this study different recommendation of control steps and upgrades applied in the chiller plant system and sensors to work together around the clock to use the least electrical power consumption without any effect on performance .

Index Terms -- HVAC, Chillers , Cooling Towers , Energy Saving , Characterization, DX-System, AHU Units , Efficiency .

1. INTRODUCTION

This study was conducted in different building of a polypropylene random copolymer (ppr) pipe processing manufacturing plant which makes its own resin in-house and uses it in molding and extrusion operations. The facility occupies manufacturing plant, laboratory, warehouse and office space. The plant currently employs close to 860 employees that work over a period of three shifts per day and seven days per week . The building built in 2006 and equipped with water- cooled air-conditioning system complete with air handling units (AHU) in different sizes and with a range of configurations . In this paper , electrical consumption by chillers , cooling towers , pumps and air handling units for the buildings and offices of the factory estimated 38% of total electrical consumption of different percentage of loadings .The aim of this study is to achieve a control in operation in a multi-chiller plant to show the considerable improvements in efficiency which reduces electrical consumption and maintenance costs. The contribution of this paper is a proposal investigates of many modifications to the multi - chiller plant . As a result , noteworthy improvement on electrical saving obtained after applying the recommended modification points. All readings calculated and quantified . It has been estimated that about **12,176,368 kwh** annual electrical energy can be saved by using the recommended modification points explained in the study . About **4,848** metric Tons of CO_2 emission could be also avoided.

2. FACILITY DESCRIPTION :-

The factory is located in state of Kuwait, which is located 30 km in distance of Kuwait City. Since, the weather conditions data of Kuwait City was pulled and tabulated.

The data is for the year 2018, where it consists of monthly temperatures, relative humidity, cooling degree days, heating degree days, and wet bulb as represented below in table (1) "Ref [4]".

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(Table1) Kuwait Weather Conditions of 2018

Month	Temperature		Relative Humidity
	°C	°F	%
January	17	62	63%
February	19	67	66%
March	24	76	58%
April	29	84	55%
May	35	95	71%
June	39	103	69%
July	41	106	74%
August	42	107	59%
September	38	101	65%
October	32	90	72%
November	24	76	68%
December	18	64	58%

3. COOLING SYSTEM DESCRIPTION :-

The process/clean areas are served by air handling units (AHUs), which typically have outdoor air inlets, return air inlet, pre-filters, chilled water cooling coils and bag filters. Some units fitted with variable speed drives supply fans .Other AHU's have HEPA filters and return fans. Local GMP's require a minimum of (20) air changes per hour . levels are set by the periodic, manual adjustment of outside air dampers. The AHU's typically run (24) hours (7) days per week. AHU's serving areas with extended production shutdowns are turned off. The offices, laboratories, and support areas are served by roof-top units (RTU's) with direct expansion (DX) refrigerant cooling. This equipment is typically started and stopped by an energy management system and run from (08:00 to 17:00) hours ; Monday through Friday. The HVAC chilled water system is a primary flow chilled water system with stepped capacity control based on the number of chillers manually selected to run. There are (5) water-cooled and (1) air-cooled chillers as listed in the chart below.

(Table2) Model and Capacity of Chillers at Factory For HVAC and Process Cooling

Equipment ID	Equipment Type	Manufacturer Model #	Max. Electrical Load	Capacity	Chilled Water		
				Tons	Inlet Deg.F	Outlet Deg.F	Gals/Min
#1	Water-Cooled Centrifugal	Trane CVHF770	436 kW	770	56	44	1600
#2	Water-Cooled Centrifugal	Trane CVHE500	259 kW	500	55	45	1476
#3	Water-Cooled Centrifugal	Trane CVHF770	448 kW	770	56	44	1600
#4	Water-Cooled Screw	Trane RTHA450	313 kW	450	53	45	1500
#5	Water-Cooled Centrifugal	Trane CVHE500	259 kW	500	53	45	1266
#6	Air-Cooled Scroll	Trane CGAM052	160 kW	52	44	38	176

The six (6) chillers comprise four chiller plants. Chiller Plant (1) has 2 Chillers(#1 and #2) . This chiller plant provides cooling to the air handlers and processing lines and has a free cooling heat exchanger. It has two cooling towers each with fans on VFDs (CT-1 & CT-2) and (3) 25-HP cooling tower pumps (TWP-1, TWP-2 & TWP-3). The cooling towers provide cooling for the air compressors. It has two chilled water return pumps on VFDs (CHWP1 & CHWP2), and (1) 25 HP chilled water supply pump (Air Compressor Cooling Pump) to the air compressors .

Chilled plant (2) has two chillers (4 & 5).This chiller plant provides cooling to the air handlers (AHU) and has a free cooling heat exchanger . It has two cooling towers each with fans on VFD_S (East & West) and (3) cooling tower pumps TWP-5 [40 HP] , TWP- 6 [40 HP] & TWP – 7 [60 HP] .

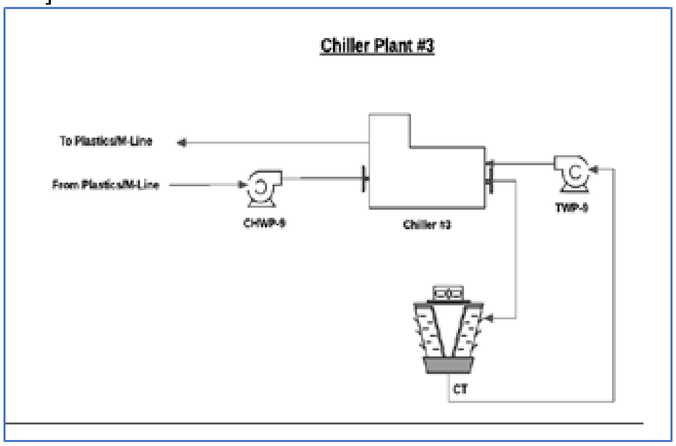

Fig. 1 . Schematics for the layout and piping for the chiller plant 3

It has two chilled water supply pumps on VFD_S . CHWP 4 & 5 and two [30 HP] chilled water return pumps (CHWP- 6 &7).Chiller #5 was out of commission and not operating since August , 2016.

Chiller Plant (2 has) has two chillers (4 & 5) . This chiller plant provides cooling to the air handlers and has a free cooling heat exchanger. It has two cooling towers each with fans on VFDs (East and West) and(3) cooling tower pumps (TWP-5 [40 HP], TWP-6 [25 HP] & TWP-7 [60 HP]). It has two chilled water supply pumps on VFDs (CHWP4 & CHWP5) and (2) 30-HP chilled water return pumps (CHWP-6 & CHWP-7). Chiller #5 was out of commission and not operating since August, 2016.

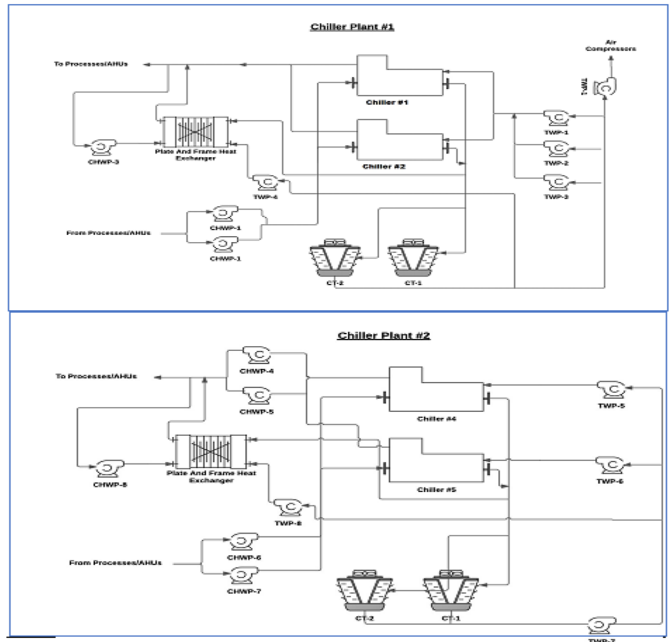

Fig. 2 Schematics piping layout for the chillers plant 1& 2

In addition to the chiller plants , there is a cooling tower dedicated to provide cooling to the plastics extrusion process . the plastics cooling tower has 1 fan on VFD (CT-1) and (CT -2) of (40 HP) cooling water supply pumps also on VFD_S (TWP -1 & 2) .

4. STUDY METHODLOGY :-

A proposed data collection approach was defined , manual tests and BMS logs used for all data collection. Also information from other variables , such as ambient temperature , chiller diversity load ratio , evaporating and condensing temperature and pressure , motors current , .. etc , considered for the study . Data collection provides Readings and information about individual chillers and , on other hand , data about the complete chiller plant .This is to study performance of each individual chiller and whole plant to enhance the complete plant efficiency. Parameters and data extracted from individual chiller is used to apply all modifications to chiller functions to improve their operation and reduce power consumption "Ref [2]" . At the same time , data –driven from whole plant and analyzed for the purpose of obtaining global understanding about the chiller plant .Using the readings and data extracted from chiller plant , numbers of technical modifications proposed to control parameters of the chillers for improving the efficiency and reduce the electrical power consumption .

(Table 2)Summary of combined chillers system operation load at the plant.

ΔT	2.63	°C
	4.74	°F
Average Load	919	kW
	1,912	Ton
Max Load	1,267	kW
	2,535	Ton
Efficiency	7.33	COP
	.48	kW/Ton

The following chart shows the base line energy consumption and cooling load provided by the chillers. AS the graphs clearly illustrate, as the chiller load fluctuates, all the chillers change their capacity to provide the required load. None of the chillers are in a base load / trim sequence strategy

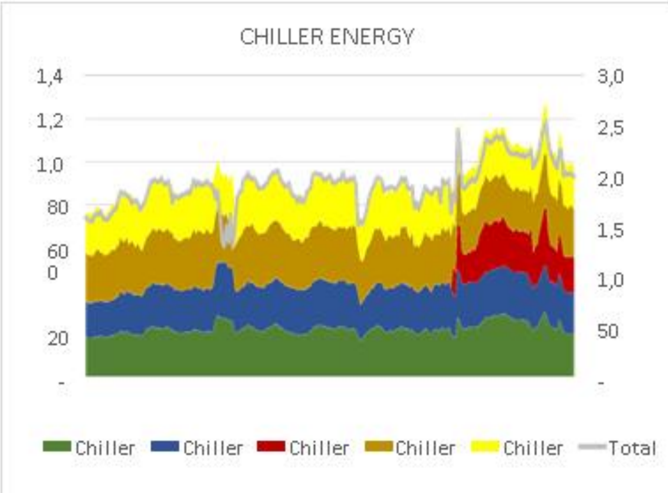

Fig . 3 chart shows the base line energy consumption and cooling load (tons) provided by the chillers

5. RECOMMENDATIONS TO INCREASETOTAL EFFECIENCY OF THE CHILLER PLANT :-

In this section, the recommendations of the cooling system "Ref. [5] will be discussed in further length as well as the methodology of implementation. The following recommendation items that will be discussed.

5.1 . Add VFD with PID pressure control for CTWS pumps and add isolation valves to equipments

Currently, a single (50 hp) pump supplies cooling water for the compressed air plant. This pump is a fixed speed and is generating (51 psi.). Opportunity exists to reduce the speed of the pump, as the system requires (44 psi) at the head to operate. Additionally, the compressors and Dryer (#6) do not appear to have isolation valves. Cooling water continues to flow through them in periods when they are idle. The recommendation is to add a VFD to the CTWS pump, and to have the system modulate speed based on feedback from the pressure transducer of the supply header to maintain (44 psi.) . Many VFDs exist on the market where they can have (4- 20ma) signal from a local pressure meter and modulate to the pressure set-point.To reduce the needed pump volume, isolation valves can be added to the Compressors. A normally open valve is installed, that closes via a relay. The relay switch is tied into the run signal from the local control panel for the compressor or dryer.The cost of ($20,594) includes the installation of a (VFD) on the pump, a discharge line pressure transmitter, and eight (8) normally open solenoid valves. The pump savings realized will be (172,827 kWh/year) or ($12,201).

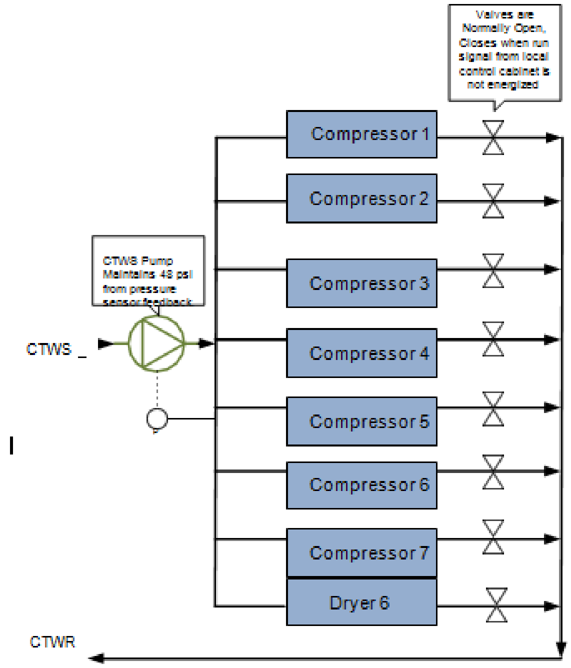

Fig . 4 Layout VFD with PID pressure control for CTWS pumps and isolation valves to equipments

5.2 . Outside Air Treatment for Clean Rooms

Currently the plant has a lot of openings through the clean rooms that causes pressure reduction throughout the room, this loss in pressure has to be made by introducing outside air into the room, which cost the plant a reasonable amount of energy due to air treatment condition. This project includes sealing any openings and includes replacing plastic strips with a sliding window that's already been used throughout the facility. The electricity savings from sealing the opening and installing a sliding glass window is (923,567 (kWh/Year) or ($65,199) per year at an estimated cost of ($80,000.)

5.3 . Reduce Clean Rooms AHR to the minimum required based on particle count

Currently the plant clean rooms Air Changes per Hour (AHR) are varying widely and exceeding the minimum requirements for the class specified " Ref [8]". The recommendation is to lower the air changes and rebalance and validate the different clean rooms to meet the minimum required air changes for the specified areas below. The savings are achieved with the reduced air flow and cooling requirements. The anticipated savings are (694,146 kWh/Year) or ($49,003) at an estimated cost of($40,000) to implement. The cost includes tying in existing humidity sensors into the existing Energy Management system and adding the control logic to manage the airflow to meet the required air changes.

(Table 3) Shows AHR changes and saving achieved with the Reduced airflow

AHU Id / Location	Motor Size (HP)	Flow (cfm)	Hours/yr	Actual Air Changes/hr	Proposed Air Changes/hr	Saving kWh/yr	Saving $/yr
HVAC 96/ room211	30.0	10,200.0	8,000	24	15	61,487	$4,366
HVAC 96/ room274	40.0	27,600.0	8,000	21	15	66,966	$4,755
HVAC51/room282	35.0	16,000.0	8,000	18	15	21,989	$1,561
HVAC 99/room 24	41.0	12,000.0	8,000	25	15	35,148	$2,495
HVAC/ room 362	20.0	7,600.0	8,000	28	15	39,585	$2,811
HVAC/Room370	15.0	6,800.0	8,000	35	15	40,667	$2,887
HVAC molding/377/378	50.0	41,000.0	8,000	22	15	225,774	$16,030
HVAC 72/ 187/188	41.0	13,000.0	8,000	32	15	92,482	$6,566
room 383	30.0	9,500.0	8,000	61	15	87,085	$6,183
HVAC 79/ room 198	7.5	5,000.0	8,000	61	15	22,964	$1,630
						694,146	$49,284

5.4 . Optimize Chiller Sequencing

The chillers should be operated in parallel and should have the Tracer control system maintain the temperature while insuring that each chiller is staged to be fully loaded before another chiller is added. The control system should sequence the chillers automatically based on load with a new updated strategy and installation of flow meters. The chillers should be managed to prevent any one chiller at each plant from running at part load conditions if a better combination of chillers is available. The efficiency of the chiller system will improve from (0.48 kW/ton to 0.43 kW/ton). The savings of (789,318 kwh/yr or $55,721) has no interactive affect with the free-cooling measure. The free-cooling measure describes the interactive effects if chiller sequencing and free-cooling are combined. The costs associated with this measure includes modifying the control strategy of the chiller sequencing program in the existing Energy Management System and local controllers.

5.5 . Implement wet-bulb following for cooling tower fans

The fans in the cooling towers have VFDs but are set on a fixed set point based on tower water temperature. By programming the VFDs on the cooling tower fans to control speed based on wet bulb and a pre-determined approach temperature will optimize the speed of the fans and reduce energy consumption. The savings from improved control of the cooling tower fans will result in a fan energy reduction of (410,169 kwh/year or $28,956 per year) . The cost includes modifying the controls strategy in the existing Energy Management System and local controllers

5.6 . Chiller Pump VFDs Installation and Optimization

It is proposed that variable frequency drives be installed on Chiller Plant #2 , CHWP #6 and CHWP #7 pumps to optimize their usage and minimize pumping energy by adjusting the flow based on load. The balance of the chilled water pumps that are already on VFDs should be optimized. The sequencing strategy is such that the pumps' speed will be based on chilled water load as measured by flow meters and differential temperatures between the supply and return lines. The idea behind the strategy is to reduce the pumps speed when the chilled load is low as indicated by a small differential temperature. Expected savings are (440,785kWh/year) or ($31,117). The cost of ($15,500) includes the installation of three new chilled water flow meters, integration into the existing Energy Management System, and modifying the control strategy in the control system.

Fig . 5 shows pumps VFD_S

5.7 . Install VFDs on cooling tower pumps

The existing pumping system in cooling tower consists of pumps operating at constant power. This uses more energy than required, providing an opportunity for energy savings. The proposed condition will install variable frequency drives on the cooling tower pumps to control the flow of the pumps based on the cooling requirements measured by differential temperature. The flow will be maintained such that minimum flow conditions are met at about 30% pump speed. The expected savings are (579,905 kWh/yr) or ($40,938.) The cooling tower pumps are as follows:

Chiller Plant 1: TWP-1, TWP-2 TWP-3
Chiller Plant 2: TWP-5, TWP-6, TWp-7
Chiller Plant 3: TWP- 9

The ($92,500) cost for the system includes installation of VFDs on each pump and modifying the control strategy in the Energy Management System to control the pump speed based on a fixed temperature differential between supply and return temperatures.

5.8 . Optimize Free Cooling

Free Cooling reduces refrigeration energy consumption "Ref. [5], [9]" by using evaporative cooling equipment to produce chilled water. When the ambient air temperature drops to a set temperature, a modulating valve allows all or part of the chilled water to by-pass an existing chiller and run through the Free Cooling system, which uses less power and uses the lower ambient air temperature to cool the water in the system. The work would require the installation of a free cooling heat exchanger and new piping.

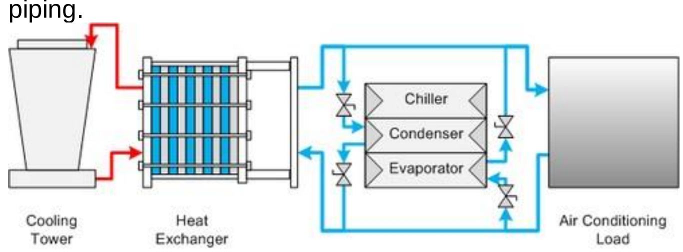

Fig. 5 Free Cooling Design Layout

Optimize the operation of the water-side free-cooling systems already installed in Chiller Plants(1) and (2). Maximize the use of the evaporative cooling capacity of the cooling towers to produce (47°F) chilled water for approximately (1,000) hours during the winter months. The project would include install new control valves to automatically direct the water flow as required to accomplish the proposed design and install new outside air and wet-bulb temperature sensors. For chiller plant #1, installation of 3-way valve on compressed air cooling loop is required. These savings of (653,488 kwh/year) are based on free-cooling versus no free cooling. No data was available to determine how much free cooling is done. If free cooling and chiller sequencing are both implemented the savings will be reduced by (20%) for each measure due to interactive affects and elimination of double counting of savings.

5.9 . Retro Commissioning of Chillers and AHU Controls

By implementing a retro-commissioning (RCx) effort that verifies readings of all sensors and confirms operations of all control devices in the Chiller and AHU system .It will re-instate the systems to the original design intent and sequence of operations. Retro- commissioning is a systematic and documented process for identifying no- and low-cost improvements that can boost the efficiency and performance of the HVAC and chilled water system. This will also help to identify changes that have taken place within the facility but have not yet been addressed or implemented by the Trane system due to the facilities always being in a state of flux. The savings are estimated at (5%) of the chiller system energy costs and should provide a reduction of (447,720 kWh/yr or $31,606) . The ($30,000) cost includes a controls integrator onsite for 20 days to confirm proper operation of all sensors and strategies and includes a ($10,000) budget for necessary repairs to instrumentations and controlled devices.

Fig. 6 . Sample of retro commissioning set

5.10 . Implement Advanced AHU Controls

Implement advanced air handler controls to include the following:

1.Air-side economizers on air handlers to bring outside air into the plant during cool outside air temperature. If the outside air is particularly cold, the economizer should be well mixed with the exhaust air so its temperature and humidity fall within the desired range for the process or space.

2.Some of the cooling and heating coils used for space temperature are controlled by space temperature sensors. These should be changed to be controlled by return air temperature to reduce the large hysteresis, or delay in the controlled response to temperature input.

3.Currently, air handlers are controlled by balancing the rooms and manually setting the damper positions and supply fan speeds. Motorized actuators and flow controls should be installed to control the fan speed based on actual flow rate into a space and return or exhaust damper position to control differential pressure in rooms.

Implementation of this measure will reduce the cooling load on the chillers by optimizing cooler temperatures of ambient conditions when applicable and will save (2,481,091 kwh/yr or $175,151) . The ($342,200) cost of this measure includes installing or repairing actuators for controlling outside air flow, temperature and humidity sensors andvelocity meters on all AHU's, and tying them into the Energy Management System

Fig. 7 Advanced air handler controls

5.11 . Replace Heat Exchanger at Palletizer 47 & Tubing Process

There are sensors installed throughout the chilled water loop that measures the differential pressure across (DP) the supply and return lines. The chiller control system evaluates the values of the DP of each sensor and controls the chiller plants' supply pump speeds based on the lowest DP value in the chilled water loop in order to maintain a minimum DP. Two heat exchanges at Palletizer (47)and the tubing process are uncontrolled and have very low differential pressure and contributes greatly to low DP in the chilled water loop. By increasing the differential pressure across the HXE, approximately (203,378 kWh/yr or $14,357) will be saved. Ideally the heat exchangers should be replaced; however, the price of replacement would make this measure not financially feasible. The alternative is to restrict the flow through the HXE with the use of 2-way valves or orifice plates. The ($21,000) cost of this measure includes the installation of 2-ways valves, pressure sensors, and the control strategy to many the differential pressure drop.

5.12 . Install Humidity Control for new molding area and eliminate warehouse cooling

The new West Molding Clean Room had moisture issues during the summer due to very low heat loads in the space and no humidity controls in the four (4) air handlers for the space. The quick solution was to cool down the surrounding warehouse space and use the cooled air from the warehouse to supply the air to the rooms. This is not a good long-term solution due to dependence on the warehouse conditions and needing to cool a large space that normally does not need to be cooled. The proper solution would be to de-couple the warehouse air from the clean room air and add humidity control to the four (4) molding air handlers by either installing duct heaters or desiccant wheels with the proper controls to maintain an acceptable humidity range. The savings for this measure are(174,912 kWh/yr or $12,348). The ($41,800)cost of this measure includes the cost of duct heater installation, humidity sensors, integration into existing control.

5.13 . 2-Way Valves

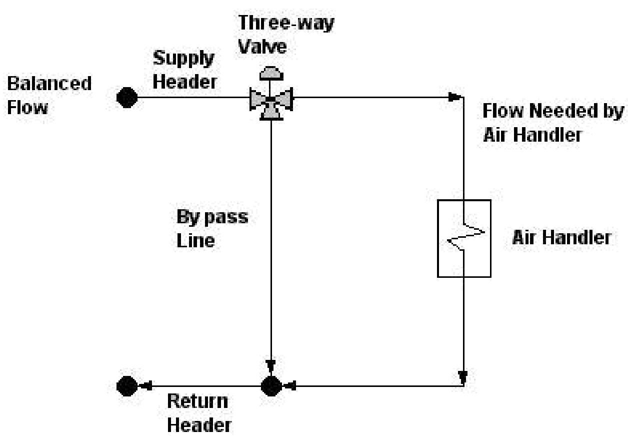

Fig. 8 show conventional 3-way valve location

The existing pumping system on the chilled water system through the air handlers and process heat exchangers uses a three-way valve as shown in the illustration below. Most systems are designed to have a 10-degree temperature differential between the supply and the return header. The water flows from the air handler through the return header, through the pump, then through the chiller to cool the water and then out through the supply header. If the space is in need of cooling the thermostat will tell the three-way valve to allow cold water to flow to air handler. In the event there is no need for cooling, then the water will be diverted back through the bypass line. This will usually cause a degradation in the temperature differential below the 10-degree design causing the chiller to have to work harder than necessary.

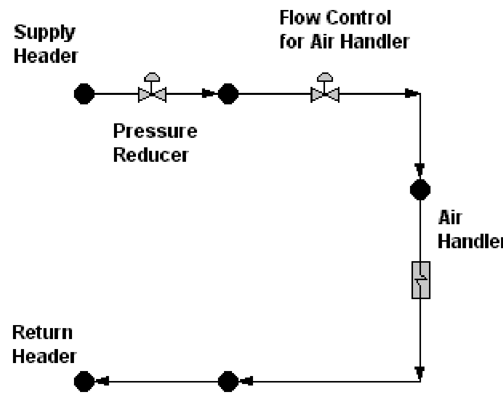

Fig. 9 show proposed 2-way valve location

The proposed scope of the retrofit will replace the three-way valve witha two-way valve, and will include the better control of the variable frequency drives (VFD) on the pumps. The position of these valves should be controlled by a room or process temperature set point. As cooling needs change, the VFD will modulate the speed of the pump to meet the required water flow. Rather than running the system at full speed at all times, the VFD enables the pump to run at lower speeds when cooling needs are low, thereby lowering power consumption. See the illustration in figure 9. For those "wild coils" that are impractical to have controlled by the Trane system, Belimo Energy Valves should be installed that have their own processor to maintain proper flow. The expected energy savings for this measure is (173,642 kWh/yr or $12,258) .The ($40,000)cost of this measure includes the installation of the 2-way valves and integration into the Energy Management System.

5.14 . Remove honeycomb air flow stations in 6 AHUs

Six (6) air handlers on the CSI system had honeycomb air flow stations originally installed. These air flow stations are no longer used, have fouled and are creating unneeded pressure drop across them, resulting in savings of (97,831 kWh/yr or $6,906). They should be removed to allow for better air flow. The($33,600) cost of this measure includes the removal and disposing of twelve (12) air flow stations.

5.15 . IMPLEMENT TEMPERATURE SET POINT SETBACK ON OFFICE SPACE

A setback control strategy should be employed to reset the cooling and heating temperatures of the office spaces and conference rooms during non-working hours, resulting in savings of (18,678 kWh/yr or $1,319). The ($4,000) cost of this measure includes implementing a control strategy that incorporates scheduled setbacks.

5.16 . Replace Return Fan Motors on 6 AHUs

Six (6) of the air handlers have return fans that have motors that have burned out. These motors should be replaced with super-high efficiency motors and turned on so the return blowers can operate properly. Currently, the supply fans are carrying the full load and, once the return fans are operating, the speed of the supply fans can be reduced substantially exponentially realizing energy savings on the VFDs because of the affinity laws. The new motors should be rated Premium Efficiency with a nameplate motor efficiency of at least(94.5%), resulting in a savings of (141,808 kWh/yr or $10,011) . The ($7,200) cost includes replacement of the motors and commissioning the system so all the blowers operates as originally intended.

5.17 . Expand Energy Intelligence

The Trane system has a powerful historian database that is not effectively being utilized by the plant. The historian should be expanded to include more HVAC and chiller data points, as well as storing boiler, compressed air, and other important energy and process data. The data should then be utilized to perform the following:

1.Create more robust dashboards that can be viewed in 2.Generate daily reports automatically to summarize the day's energy consumption (total kwh, therms , gallons, efficiency of systems- kW/tons, and KPIs) based on unto of energy per unit of production (kw/unit)3.Send alerts via fault detection & diagnostics .

he three primary source of the (204,523 kWh/yr or $14,438)savings from RCx will be realized through the following processes:

1.Decrease Operations and Maintenance effort and costs.

a. Facilitate ongoing recommissioning of systems to ensure persistence of savings.

b.Identify root causes to poor system performance.

c. Extend the useful operation lifecycles of equipment and systems.

2.Increase indoor environmental quality and occupant comfort.

a. Verify that adequate air flows and proper space temperatures are being maintained in occupant spaces.

3.Realize immediate and long-term energy savings and peak demand savings.

a. Optimize how the facility's energy using systems are operated and maintained.

b.Identify previously unrecognized inefficiencies in building and plant system operations.

C .Measure and document energy savings from resulting operational improvements.

(Table 4) summary of electrical consumption saving & project cost &payback

6. CONCLUSION :

The application of the suggested modification points and the methodology, great power consumption and efficiency enhancement obtained in chiller plant .Study applied on a running chiller plant at the pipe manufacturing factory(Kuwait) . Recorded readings and knowledge about chillers operation given enabled to apply the needed moderations and adjust detected faults and inefficient operation . Table (4) summarizes results and comparison between collected data and previous readings before changes . It is calculated that about(**12,176,368 kwh /year)** annual electrical energy can be saved by applying recommended modification points explained in the study . About (**4,848**) metric Tons of CO_2 emission could be also avoided .

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