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Recommissioned energy control strategy for RTÉ Television Centre's chilled water system



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Abstract

This paper investigates the energy performance of a building's chilled water system (CHWS), primarily focusing on the systems direct electrical energy consumption and the potential for delivering improvements to increase the overall operational efficiencies of the CHWS. The CHWS supplies the cooling energy requirements of the RTE Television Centre's Air Handling Units (AHU's). This paper presents a detailed energy audit of both the current cooling energy load and the CHWS, while outlining a cohesive control strategy that focused on reducing the CHWS load by implementing free cooling methodologies for the building's AHUs. The paper continues by presenting a descriptive analysis of the CHWS operational characteristics and the resultant energy savings achieved by the development of an innovative control strategy which allowed for demand-led modulating control of the CHWS.

The result is an overall reduction in the operation of the CHWS of approximately 44% equating to an annual reduction in operational hours of 2956 hours.

An overall energy saving of 691,000 kWh was made in the first year of operation between the CHWS and the AHUs.

Key Words:

Modbus Interfacing; Air Handling Unit; Building Management System; Temperature Lift; Enthalpy Control.

1. Introduction

The primary energy model that this paper focuses on is based on the overall energy requirements that CHWS place on a building's energy map. As energy cost is a primary expense for businesses, a reduction in energy consumption will lead to a reduction in their operating cost base, ultimately leading to a more profitable business model. The objectives of this project were primarily to reduce energy consumption by defining new chiller control strategies and tuning control loops for the existing CHWS, while maximising the use of the existing building management system (BMS) as a control tool for enhancing energy control and monitoring for the CHWS. The project also incorporated energy efficient methodologies in order to deliver a more efficient operation of the CHWS.

1.1 Project background

The CHWS serves the TV building which is a two-storey building with basement and roof plant space. The building was built over two phases (1962 and 1979) with a further extension in 1990. It houses all the main TV studios along with technical and administrative areas supporting the full TV production process. There are a number of different modes of use for the chilled water from the original dual duct, multizone to more modern fan coil circuits. The critical loads include live transmission TV studios which rely heavily on the safe and secure delivery of chilled water to ensure uninterrupted transmission on many of the stations flagship live programs. While RTE are committed to energy saving there is a constant requirement to balance this objective with the primary business function of delivering uninterrupted transmission across all its different media platforms. The CHWS forms a vital component in this function.

2. System description

As illustrated in Fig. 1 the CHWS consists of two sets of chillers, each of 745kW cooling capacity and each chiller is commonly coupled by three primary and secondary condenser water pumps, four building chilled water pumps and two cooling towers. Each chiller has two compressor circuits, and each is factory fitted with a dedicated CAREL interface which monitors and controls the chillers to initial setpoints of 7°C. The CHWS initially operated 18.5 hours a day, seven days a week, 365 days a year. The system provides the cooling energy requirements for the Television Centre's heating, ventilation and air conditioning (HVAC) systems.

Table 1 illustrates the associated CHWS plant, while also outlining a daily energy usage for the CHWS of 7106kWh, which the initial feasibility audit produced. The table information is based on an ASHRAE level 1 audit structure which is an entry level audit, analysing the respective plant items by acquiring the rated plant information from local data plate attached to the relevant plant. The site's BMS initially had limited control of the CHWS, and only allowed for a system stop/start function by way of a time schedule.

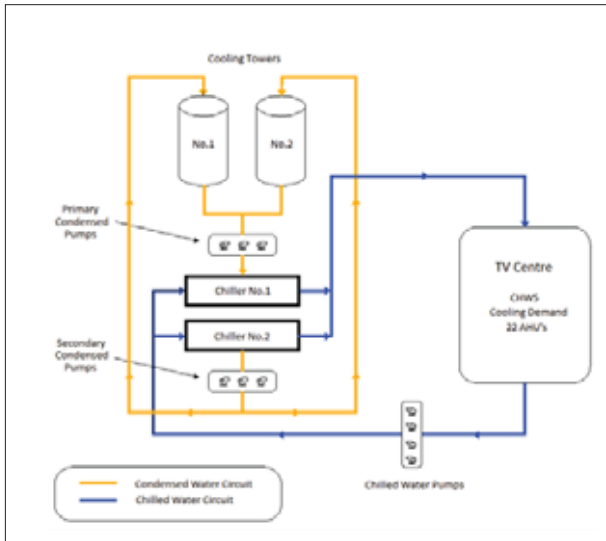


Fig. 1 – Block diagram illustrating the CHWS layout and associated plant items.

The BMS also monitored and data logged various system temperature sensors such as condenser flow/return, chilled water flow/return and the cooling tower temperatures, while also monitoring certain alarm conditions including primary/secondary condenser pump faults, building chilled water pump faults and general alarm points from each of the chillers.

3. Areas of research

The following areas of investigation were deemed by the researcher as the most important in terms of the efficient operation of the CHWS and which ultimately delivered an energy reducing energy strategy.

- Potential for a reduction in the CHWS operational hours, by introducing more stringent time scheduling for the Television Centre's AHUs, ultimately reducing the cooling load demand on the CHWS.
- Potential for enhanced BMS strategies, focusing on demand-led engineering, which has the potential for significant energy saving through efficient operation.
- Potential for the introduction of Modbus interfacing between chillers and existing BMS to maximise the effectiveness of the BMS control strategy. The inclusion of this type of interfacing is expected to broaden the scope of control capabilities of the CHWS.
- Potential for the improvement to the operation and efficiency of the chillers, in particular the relationship between condenser and evaporator water temperature.

4. Energy audit

The aim of the energy audit was to identify how both the building AHUs and CHWS uses energy, and ultimately produce recommendations of improvement measures that allowed for the development of an effective energy strategy for the CHWS.

4.1 Cooling load – air handling units

The Television Centre's AHUs have the following operational characteristics:

- The Television Centre has 22 AHUs installed throughout the building which all require a cooling energy source for the operation of their respective cooling coils.

Table 1: Associated chilled system plant and initial daily energy ratings: taken at project feasibility stage and provided background information of the CHWS.				
Plant Item	Plant Rated Data			
	Rated (kW)	Efficiency	Input (kW)	kWh
Condense Pump 1(Pri)	18.5kW	0.84	22kW	407kWh
Condense Pump 2(Pri)	18.5kW	0.84	22kW	407kWh
Condense Pump 3 (Pri)*1	0kW	0.84	0kW	0kWh
Condense Pump 1(Sec)	11kW	0.87	12.6kW	234kWh
Condense Pump 2(Sec)	11kW	0.87	12.6kW	234kWh
Condense Pump 3(Sec)*1	0kW	0.87	0kW	0kWh
Chilled Water No.1	22kW	0.9	24.4kW	452kWh
Chilled Water No.2	22kW	0.9	24.4kW	452kWh
Chilled Water No.3	22kW	0.9	24.4kW	452kWh
Chilled Water No.4	22kW	0.9	24.4kW	452kWh
Chiller No.1	90kW	1	90kW	1665kWh
Chiller No.2	90kW	1	90kW	1665kWh
Cooling Tower No.1	18.5kW	1	18.5kW	342kWh
Cooling Tower No.2	18.5kW	1	18.5kW	342kWh
Daily Totals (18.5Hrs)			384kW	7106kWh

- Standby pumps *1 – these pumps initially only operated on a standby cycle. Therefore they were excluded from the systems calculation
- All pumps initially taken as operational at 100% full Load
- Chillers and cooling tower – actual localised reading measured

- A typical AHU in the Television Centre consists of supply and extract fans, dampers, ducting, filters, and air inlets/outlets.
- The strategy that was initially commissioned for each AHU controlled and operated the relevant AHU to deliver the treated air by controlling the moisture content and temperature.
- The original operational requirements for all units vary, and a full operational schedule for 2009 is illustrated in Table 2.

4.1.1 Cooling load data analysis – air handling units

The primary goal of the energy audit was to reduce the cooling load placed on the CHWS by both reducing the operational hours of the Television Centre's AHUs while also enhancing the AHU strategies by utilising the free cooling potential from the outdoor climatic conditions by implementing efficient damper led control. The following improvements were made as a result of the audit findings:

- The result of stringent scheduling allowed for average savings of approximately 16% in operating hours of the Television Centre's AHUs. This was achieved without adversely affecting the thermal conditions and health of occupants within the Television Centre.
- One strategy issue uncovered by the audit was that the strategy was using an enthalpy module while the humidifier section at the AHU was decommissioned. The resultant effect was that

the strategy was using the cooling coil to dehumidify, while the humidifier section used to humidify was not operational.

- The removal of the enthalpy control modules from the respective strategies allowed for the development of a consistent energy-focused strategy in line with the available plant sections within the AHU's.
- The implementation of active damper-led control techniques allowed for the development of individual AHU strategies which maximised the free cooling potential that the outside air temperatures presented.
- Energy audit highlighted many areas of energy inefficiency within the relevant AHUs operational methodologies. One example is the installed motors for AHU No. 1 supply and extract fans, which the audit highlighted as been both oversized.

4.2 Chilled water system data analysis

The process of developing a new control strategy incorporated the monitoring of each AHUs cooling coil requirements, and using this information to control the CHWS based on developing a demand-led strategy. The following outlines the strategy format:

- Each of the Television Centre's 22 AHUs which require cooling energy was separated into two groups which formed Priority High and Low formats.

Table 2: Air handling units – resultant operational and energy data

	2009 Scheduled Hrs Vs 2010 Scheduled Hrs		Measured Load (kW) Rating	Measured Savings (kWh) Saving	
	Scheduled Hours 2009	Scheduled Hours 2010 Percentage Saving			
AHU No.1	Schedule Dependent	Schedule Dependent	21.1kW	0.0kWh	
AHU No.2	Schedule Dependent	Schedule Dependent	14.7kW	0.0kWh	
AHU No.3	Schedule Dependent	Schedule Dependent	14.2kW	0.0kWh	
AHU No.4	Schedule Dependent	Schedule Dependent	14.4kW	0.0kWh	
AHU No.5	Schedule Dependent	Schedule Dependent	13.5kW	0.0kWh	
AHU No.6	06:00hrs – 24:00hrs	07:45hrs – 23:45hrs	4.4kW	8.8kWh	
AHU No.7	06:00hrs – 24:00hrs	07:30hrs – 23:00hrs	3.1kW	7.7kWh	
AHU No.8	06:00hrs – 24:00hrs	07:30hrs – 22:30hrs	16.0kW	48.0kWh	
AHU No.9	06:00hrs – 24:00hrs	07:30hrs – 22:30hrs	19.1kW	57.3 kWh	
AHU No.10	06:00hrs – 24:00hrs	07:30hrs – 23:00hrs	3.7kW	9.2 kWh	
AHU No.11	06:00hrs – 24:00hrs	08:30hrs – 23:00hrs	1.6kW	5.6 kWh	
AHU No.12	06:00hrs – 24:00hrs	07:30hrs – 20:00hrs	20.8kW	114.4 kWh	
AHU No.13	06:00hrs – 24:00hrs	07:30hrs – 23:30hrs	21.5kW	43.0 kWh	
AHU No.14	06:00hrs – 24:00hrs	07:30hrs – 22:30hrs	10.2kW	30.6 kWh	
AHU No.15	24hr Operation	24hr Operation	24.5kW	0.0 kWh	
AHU No.16	24hr Operation	24hr Operation	6.7kW	0.0 kWh	
AHU No.17	05:30hrs – 24:00hrs	06:30hrs – 23:30hrs	5.3kW	7.9 kWh	
AHU No.18	06:30hrs – 24:00hrs	07:00hrs – 22:30hrs	6.9kW	13.8 kWh	
AHU No.19	06:30hrs – 24:00hrs	07:30hrs – 22:00hrs	0.8kW	2.8 kWh	
AHU No.20	06:30hrs – 24:00hrs	08:00hrs – 23:30hrs	6.4kW	16.0 kWh	
AHU No.21	06:30hrs – 24:00hrs	07:30hrs – 19:00hrs	3.5kW	21.0 kWh	
AHU No.22	05:30hrs – 24:00hrs	Standby	5.3kW	98.0 kWh	
	Original Hours	Revised Unit Hours	(%) Saving	Load	Total Daily Saving
	307hrs	257.5hrs	15.8%	237.7kW	484.1kWh

- High Priority are transmission critical AHUs, while Low Priority covers non-technical areas.
- Each prioritisation group has Threshold On/Threshold Off facility for the cooling coil percentage valve openings, while also allowing for Delay On facility for that event.
- This tuning facility will allow for the strategy to both cope with fluctuations in load, due to the On/Off status of the different AHU time schedules, while ensuring that the strategy provides protection to the chillers' compressors by reducing the potential for unnecessary stop/starts, which would decrease the life expectancy of the relevant compressors.
- The respective priority group setpoints can be user-adjusted to suit the seasonal operational requirements of the CHWS.

5. System integration

The introduction of Modbus control allowed this researcher to introduce a variable set point for the two chillers. The initial audit conducted recorded the following energy figures which are closely aligned to that as stated by EEBPP(2000):

- At a chilled return temperature setpoint of 7°C, a daily energy usage figure of 2103kWh per chiller was recorded.
- This figure is reduced by approximately 2% (46kWh) when the chiller operated to a return setpoint of 8°C, when a reading of 2057kWh was measured.
- Similarly, when the return temperature setpoint was set for 9°C, a saving of approximately 8% (172kWh) over the initial CHWS

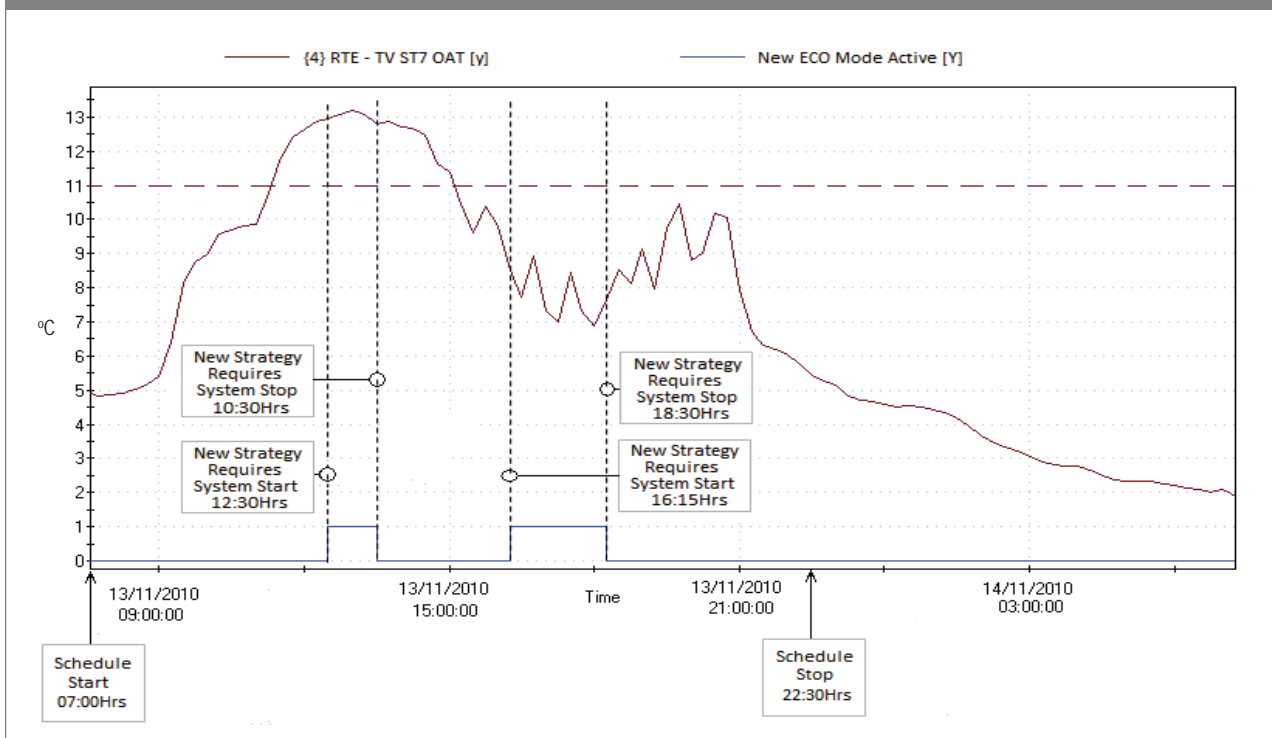
setpoint of 7°C was recorded when a reading of 1931kWh was measured.

- When the strategy varies the chiller's setpoint, dependent on the outside air temperature, achieved a significant reduction in energy usage. The chiller required 1565kWh of electrical energy when the strategy is varying the chillers setpoint, and this result produces savings of 538kWh against the initial fixed strategy setpoint of 7°C.

The resultant strategy developed and implemented is outlined as follows:

- The implementation of a variable setpoint allowing for the strategy to write a setpoint between 7°C and 11°C to each chiller, dependent on the load requirements of the Television Centre AHUs.
- The strategy determines the load based on the outside air temperature recorded on site.
- The inclusion of a variable setpoint greatly improved the systems energy consumption, by utilising the ability to increase or decrease the setpoint of each chiller.
- In winter months when lower outside air temperatures are present, the improvements to the AHU strategies primarily helped to reduce the cooling energy demand placed on the chillers.
- The introduction of a variable setpoint to the chillers also reduced the energy consumption of the chillers, particularly when the cooling load is low, because the return flow temperature can be increased to match this low outside air temperature and reduced load.

Fig. 2: BMS datalog – operation of demand led strategy: outlines a typical system response to the load requirements of the CHWS load, illustrating the system was scheduled for a 15hr operating day, but the system only operated for 3hrs 35mins, resulting in an approximate typical saving of 77% on the 13th November 2010



- The designed user interface for the BMS allows for a Mode select option based on Low, Medium or High dependent on a scaled outside air temperature of >11°C Low Mode selected, <20°C High Mode selected, and between 11°C and 20°C Medium Mode is selected.
- The Modbus then writes to the register a value between 7°C and 11°C dependent on the value of the Mode selected.
- When the OAT is at 11°C or below, the strategy will select the chiller to operate at 11°C.
- When the OAT is 20°C or greater, the strategy will select the chiller to operate at 7°C.
- When Medium Mode is selected the chiller setpoint will be scaled between 7°C and 11°C against the OAT 11°C and 20°C.
- The strategy has delay On/Off functions built in to reduce unnecessary compressor stop/starts.

Fig. 2 illustrates a datalog taken from the sites BMS on the 13th November 2010. The datalog illustrates the new operational strategy for the chilled water system, and outlines a typical day's operation for the CHWS:

- The actual cooling demand (Blue Line), which is represented by a digital signal (1 = ON / 0 = OFF).
- The red line illustrates the actual outside air conditions present in real time.
- The time schedule activates the strategy and dependent on the strategy demand status (blue line), which in Fig. 2 at startup, the demand is off.
- At 12:30Hrs the strategy ON conditions are met and the BMS initiates the CHWS.
- The system then remains on until 13:30hrs when the demand for cooling ceases and the CHWS is no longer required.
- At 16:45hrs the strategy again demands the chilled system is initiated, and the system remains on until 18:50hrs when the demand for cooling ceases and the chilled system is no longer required.
- For illustration purposes an OAT reference line is included to Fig. 2 which illustrates the LOW Mode limit strategy setpoint of 11°C.

This researcher anticipated at the initial stage of the project that the utilisation of the low outside air temperatures, typically below 11°C, would significantly increase the ability of the sites AHUs to deliver their respective cooling requirements without the aid of the CHWS.

The initial analysis for the proposed operation of the CHWS was found to be correct, and in fact the energy saving achieved with the implementation of an enhanced energy strategy for the CHWS greatly exceeded the expectations of the researcher. Fig. 2 illustrates that the system was scheduled for a 15-hour operating day, but the system was only required to operate for 3hrs 35mins, resulting in an approximate typical saving of 77% for the 21st November 2010.

6. Condenser water system

The introduction in the strategy of a variable setpoint for the condenser water circuit allowed this researcher to also reduce the operating electrical energy requirements by increasing or decreasing the cooling tower setpoint when climatic conditions allowed. Theoretically, the cooling towers on site are able to cool water to the wet-bulb temperature of the air. Therefore the cooling towers performance depends on the ambient wet-bulb temperature. The following outlines the methodologies implemented to enhance efficiencies within the condenser system.

- Modifications to the cooling towers strategy, whereby when the wet-bulb temperature drops from the designed value, due to varying seasonal climatic conditions the cooling towers will operate to more economical levels whereby the towers will provide water at lower temperatures while maintaining a fixed approach temperature. (Leaving Temp – Wet Bulb).
- The savings from the implementation of this strategy module deliver chiller efficiencies savings in the region of 2% per 1°C reduction/increase in both condenser water and evaporator water temperature setpoints.
- The strategy modulates the tower setpoint between 18°C and 22°C depending on the climatic conditions present on site.
- The low setpoint is set a 18°C and this is the optimum minimum setpoint in terms of the safe operation of the chillers.
- The manufacturer of the chillers specifies that the maximum working efficiency of the chillers is achieved at the lowest possible condensing water temperature, subject to a minimum temperature of 18°C, below which the manufacturer states that there is risk of damage to the compressors due to the refrigerant R407c sludging and this will damage both the compressor and the mechanical expansion device.

The second area that this research addressed in achieving efficiencies for the condenser water system is the implementation

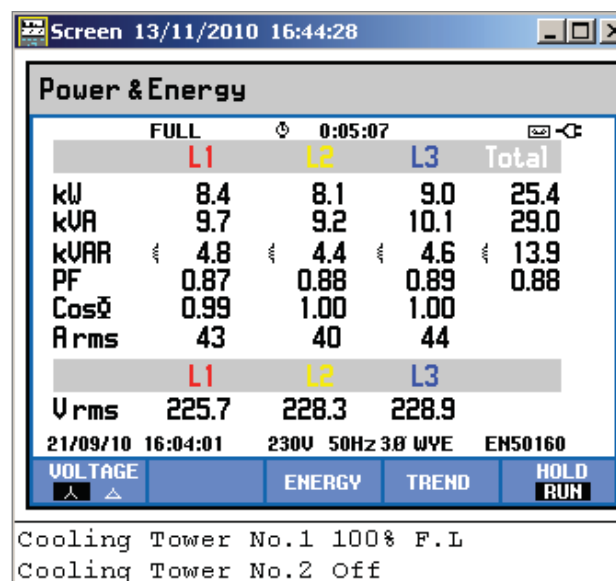


Fig. 3: Cooling Tower No.1 – energy reading @ 100% loading: energy measured when one cooling tower is operational. Measured load of 25.4kW at full load.

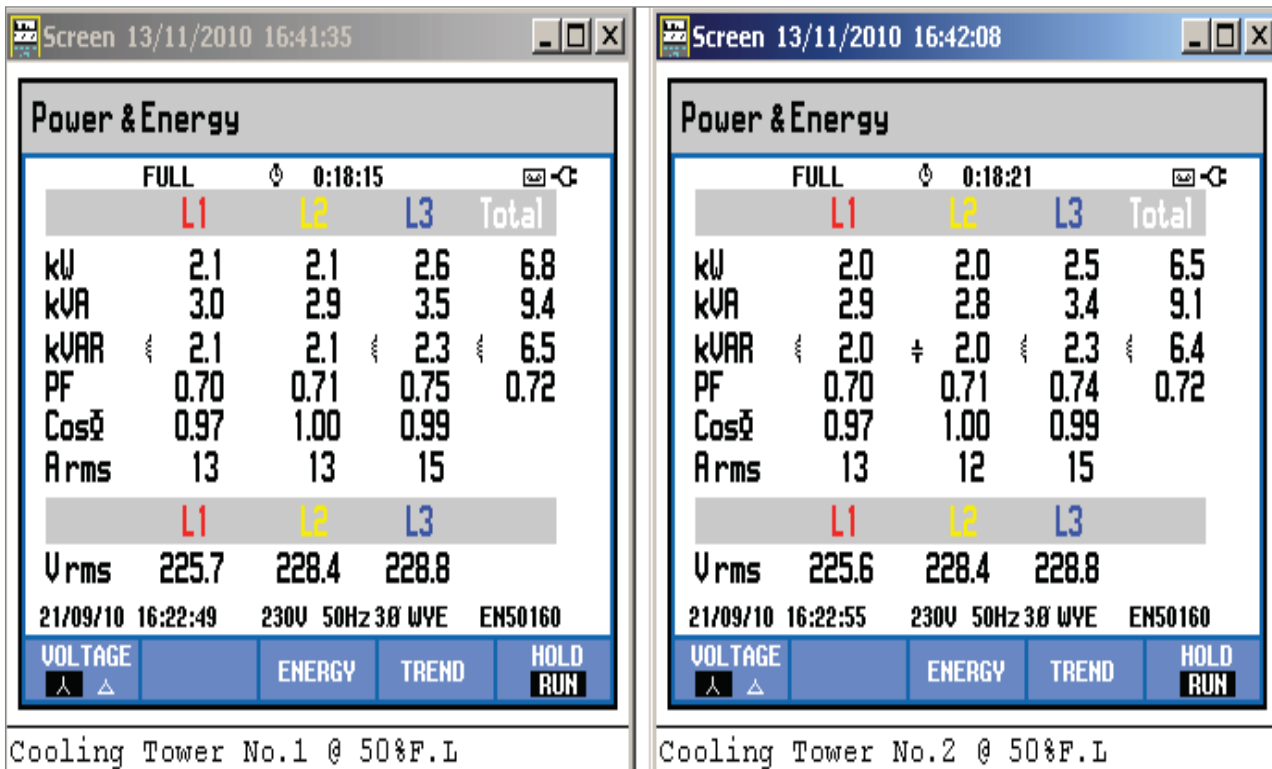


Fig. 4: Cooling Tower No.1 & 2 – energy reading @ 50% loading: re-sultant energy usage of both towers operating simultaneously is 6.8kW and 6.5kW.

technique of operating both cooling towers at the same time when required. When two towers are operating at half their fan speeds the cooling result is the same as operating one tower at full speed. Jayamaha (2006) states that the theoretical calculation for fan power consumption illustrates that the power consumption of each tower fan is proportional to the cube of their speed; the power consumption of each tower fan will drop to approximately 12.5% ($0.5^3 = 0.125$ at half speed). The result of operating both towers is a power consumption of approximately 25%, which delivers savings of 75% of the power consumed if only one cooling tower is operated.

In delivering a cohesive strategy for the CHWS this research investigated the claims by Jayamaha (2006) of energy efficiency methodologies within condenser water systems and found slightly varying results when actual local monitoring was conducted.

- This research monitored the loading on the VSD fitted to cooling tower No.1 and Fig. 3 illustrates the total power consumption recorded for cooling tower No.1 at 100% loading as 25.4kW.
- This researcher implemented a strategy as depicted by Jayamaha (2006), which operated both cooling towers simultaneously and this resulted in significant saving being achieved as illustrated in Fig. 4: This illustrates that both cooling towers only required 6.8kW and 6.5kW respectively.
- The operation of both cooling towers simultaneously results in delivering a potential energy saving in the region of 48%.
- These findings confirmed the energy saving potential as depicted by Jayamaha (2006). The 75% level of the potential savings as purported by Jayamaha was not fully achieved by this researcher on this project; however real savings of 48% were achieved.

7. Summary, findings and conclusion

In this paper an alternative energy efficient strategy for the operation of the CHWS was presented. The paper investigated the energy performance of a CHWS located at Radio Telefis Éireann which provides the cooling energy requirements for the Television Centre AHUs. The results and conclusions are summarised as follows:

- Stringent scheduling formed the initial stage in the development of a cohesive energy strategy for both the CHWS and AHUs.
- The process of developing a new control strategy incorporated the monitoring of each of the Television Centre AHU cooling coil positions and using this information to determine the CHWS status.
- This formed the framework to developing an extremely effective demand-led strategy technique.
- The strategy technique that this researcher implemented allowed for the actual cooling requirements of the Television Centre AHUs to determine the operational status of the CHWS.
- The result? – an overall reduction in the operation of the CHWS of approximately 44% equating to an annual reduction in operational hours of 2956 hours.

Table 3 illustrates the initial 2009 CHWS scheduled operational hours, while also publishing the results that the implementation of both the new energy strategy and the reduced operational hours as implemented from the energy audit.

- The implementation of stringent scheduling for the Television Centre's AHUs led to significant energy reductions of

Table 3: CHWS Operational Hours: Scheduled Hours 2009 Vs New Strategy 2010

2009 Scheduled Hrs Vs 2010 New Strategy Hrs				
	Scheduled Hours 2009	New Strategy Hours 2010	Differential Hours	Percentage Saving
January	573.5	188	385.5	67.2%
February	518	212	306	59.1%
March	573.5	251	322.5	56.2%
April	555	364	191	34.4%
May	573.5	443	130.5	22.8%
June	555	468	87	15.7%
July	573.5	477	96.5	16.8%
August	573.5	427	146.5	25.5%
September	555	410	145	26.1%
October	573.5	302	271.5	47.3%
November	555	143	412	74.2%
December	573.5	111	462.5	80.6%
Totals	6752.5	3796	2956.5	43.7%

approximately 178,000kWh. Stringent scheduling for the CHWS system led to further savings of approximately 251,000kWh. These savings required no capital investment and were easily attainable by simply implementing good energy management practices to the control and operation of systems.

- The installation of Modbus between the sites BMS and the CHWS delivered a fully-integrated control system which maximised the energy strategy control potential of the CHWS.
- The inclusion of this Modbus interfacing for the two chillers required a capital investment of €3400 by Radio Telefis Éireann, and in terms of the energy savings of 262,000kWh that this control technique assisted in delivering, was a relatively small and extremely worthwhile investment.
- The overall findings show that the energy strategy implemented to both the CHWS and the buildings AHU's produced an overall combined reduction in electrical energy usage of approximately 691,000kWh in its first full year of operation (2010).

During the course of this research several areas of system improvement within the CHWS were highlighted, and with the implementation of further capital intensive projects could deliver even more savings.

- With capital investment the inclusion of thermosyphon cooling could greatly enhance the efficiency levels of the current system.
- Given the age of the chillers, any renewal project would have to evaluate the operational characteristics of the chillers; variable speed compressors/pumps and electronic expansion devices are areas that may enhance system efficiency.

The development of the new CHWS strategy highlighted some interesting operational methodologies that developed after the initial strategy was completed:

- The inclusion in the strategy for the operation of the CHWS building pumps when the system is in LOW Mode; typically this works best during extremely cool climatic conditions whereby the strategy at start-up will circulate the existing water in the chilled water circuit.

- This allowed for utilisation of the existing cooling energy in the CHWS. This saving was not initially anticipated, but as the strategy was being developed the existing cooling energy in the chilled water pipework was highlighted, and this formed the foundation for the implementation of the energy efficiency module into the strategy
- The reduction in scheduled hours for the chilled water system was possible due in part to the introduction of enhanced BMS strategy modules, which in the case of the rescheduling of the CHWS, allowed a design whereby the building pumps would "run on" for an additional 45 minutes when the system time schedule requests the chilled system to stop, allowing the existing chilled water in the pipe circuit to continue to be distributed throughout the Television Centre.
- The implementation of temperature lift control methodologies by introducing a variable cooling tower setpoint which worked in conjunction with the variable setpoint strategy implemented for the chillers set-point ultimately allowed the BMS strategy to minimise the system temperature lift by modulating the condense water setpoint to the relevant chiller setpoint. The savings from the implementation of this condenser water reset module exceeded the chiller efficiencies savings of 2% per 1°C reduction in condenser and increase of evaporator water temperatures as stated by Jayamaha (2006).

7.1 Notable lessons learned

This paper highlights the intricate nature of energy saving within the condenser water side of the system. On that point, this research suggests that:

- In achieving lower condenser water temperatures the result is improved chiller efficiency. It should be noted that the cooling tower efficiency will be reduced due to the towers having to work harder to produce condenser water at a lower temperature, therefore the overall optimum operating point may not be at the lowest condenser water temperature.
- The implementation of a variable setpoint for the cooling tower

setpoint does not necessarily result in minimum energy consumption, since the saving in chiller energy consumption is to some extent offset by increased cooling tower fan consumption.

- The paper highlights the immediate benefits achievable on this case study when good energy management practices are implemented. Understanding of both the buildings thermal requirements and the resultant system requirements are extremely important.

It is hoped that the results outlined in this paper will benefit both building services engineers and energy managers alike, by delivering a greater understanding of the operation and design of a CHWS, and the potential energy saving measures that can be implemented for best effect.

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