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Simultaneous water and energy saving of wet cooling towers, modeling for a sample building

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Abstract. This article outlines a case study of water and energy savings in a typical building through a modelling process and analysis of simultaneous water-energy saving measures. Wet cooling towers are one of the most important equipments in buildings with a considerable amount of water and energy consumption. A variety of methods are provided to reduce water and energy consumption in these facilities. In this paper, thorough the modeling of a typical building, water and energy consumption are measured. Then, After application of modern methods known to be effective in saving water and energy, including the ozone treatment for cooling towers and shade installation for windows, i.e. fins and overhangs, the amount of water and energy saving are compared with the base case using the Simergy model. The annual water consumption of the building, by more than 50% reduction, has been reached to 500 cubic meters from 1024 cubic meters. The annual electric energy consumption has been decreased from 405,178 kWh to 340,944 kWh, which is about 16%. After modeling, monthly peak of electrical energy consumption of 49,428 has dropped to 40,562 kWh. The reduction of 18% in the monthly peak can largely reduce the expenses of electricity consumption at peak.

Keywords: water and energy saving; water and energy modeling; wet cooling towers; Simergy model

1. Introduction

In recent years, with the development of the urban construction industry, water and energy consumption in buildings has increased significantly. Saving water and energy can be an important step in achieving sustainable development in this industry (Alshamrani *et al*. 2014). Due to the fact that the role of wet cooling towers is to dissipate heat from the building's cooling system by contact of air and water, these equipments are the simultaneous water and energy consumers (Gude 2015). Simulation of the energy system of the building puts forward an appropriate approach to forecast and analyze the retrofit actions (Alaidroos and Krarti 2015, Rhodes *et al*. 2015).

It is estimated that about 768 million people around the world do not have access to good quality water (Walsh *et al*. 2015). Water, as the main component of every cooling system,

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provides heat rejection opportunity for heat exchanger networks. Thus, the quality of the cooling and make-up water needs to be considered not only to achieve an optimum operational condition, but also for reducing the negative environmental impacts (Heikkila and Milosavljevic 2001). To conserve water and treatment chemicals, it is desirable to allow the dissolved minerals to reach a maximum cycle of concentration. The cycle of concentration is defined as the concentration ratio of a soluble component in the blowdown stream to that in the make-up stream (Heikkila and Milosavljevic 2001). The maximum cycle of concentration will depend on the quality of make-up water (Parker 1998). Chemical, physical and biological treatment processes are used to improve the make-up water quality to solve the problems relevant to cooling water treatment, such as scale formation. Of all the methods, non-chemical treatment methods such as ozonation could be considered as safe and environmentally friendly methods for the use of make-up water. Conventional cooling tower water treatment technologies include treatment with chemicals to remove microorganisms and scale and the blowdown of water to remove impurities. These operations, both add to the cost of cooling tower operation and maintenance (Conner 2005). Integration of ozone water treatment with the recirculating cooling water system gathering the cycle of concentration which decreases the concentration of unsolvable components in circulating water (Viera *et al*. 2000). It intensely reduces the blowdown that, in turn, is environmentally beneficial. For maximizing water and energy conservation, ozone treatment should be integrated into the cooling tower (see Fig. 1). Application of ozone treatment in wet cooling towers began in 1985 (Panjeshahi and Ataei 2008) and its impacts on saving water and energy, reducing chemicals consumption and reduction of environmental pollution have been studied (Panjeshahi *et al*. 2009). A number of studies have been conducted from 2005 to 2010 by Ataei *et al*. (2010) in which modeling of ozone treatment in wet cooling towers has been done and the results of reduced water consumption and increased energy efficiency performance have been reported.

Furthermore, overhangs and fins, with casting shadows and hence reduction in cooling requirements, could decrease the electrical energy consumption of the buildings (Boji 2006). The impact of overhang and side fin installation on the amount of radiation received during different hours and months of the year have been studied and the results have been reported by Maestre *et al*. 2015. It was found that appropriate overhangs or fins installed in the south, west and east windows would lead to an optimal reduction of the annual energy transferred into the buildings and have an

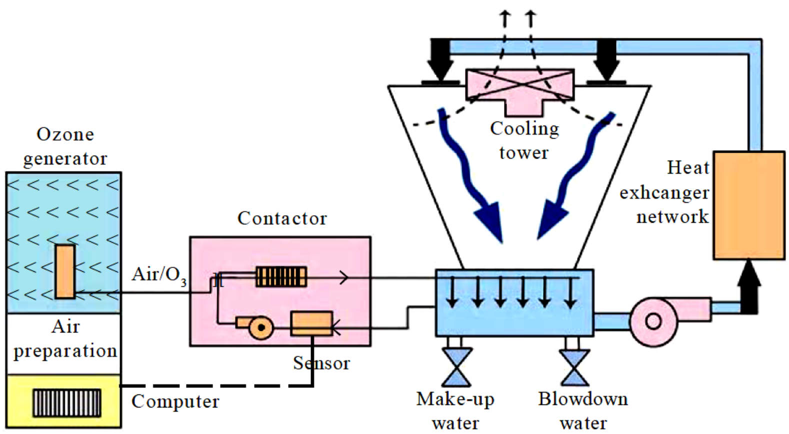


Fig. 1 A schematic of integrating ozone treatment into the cooling tower

energetic behavior equivalent to high performance glazing (Ebrahimpour and Maerefat 2008).

None of the earlier studies has addressed a comprehensive analysis (simultaneously) of saving water and energy by offering these two solutions. This study, puts an emphasis on the impact of operating conditions of wet cooling towers in buildings, by means of a comprehensive analysis of water and energy savings in a typical commercial building. By application of ozone treatment of the circulating water, the blowdown of the cooling towers has been reduced from 33% to 5% of the total water. Overhang and side fin installed on windows have increased energy efficiency and reduced water consumption in the cooling tower of the observed case.

2. Materials and methods

2.1 Simulation software

Simergy is a significant improvement on existing EnergyPlus graphical user interface tools in terms of user workflow and productivity. The strong interest in Simergy in the architecture and engineering community and the new role of EnergyPlus as the primary reference model for Title 24 indicates that Simergy can be expected to increase the use of EnergyPlus by design practitioners. Use of EnergyPlus enables the design of more efficient buildings than the other simulation tools based on the DOE-2 engine because EnergyPlus supports the analysis of a wider range of low energy systems, including natural ventilation, radiant cooling and underfloor air distribution. More energy-efficient building design is expected to lead to lower actual building energy consumption, which benefits by helping to mitigate climate change, reduce air pollution and reduce utility bills (Haves *et al*. 2014).

2.2 Detailed simulation procedures

For the modeling, at first, the building information has been entered Simergy model and water and energy consumption have been obtained. The building is located in an area under the conditions provided below. The site around the building has been designed to determine the position of the building regarding the radiation level and wind. Then the building plan has been introduced to the model.

Simergy has graphical tools for creating diagrammatic representations of HVAC systems. These tools enable the user to edit predefined templates or to create new system descriptions that resemble conventional mechanical system drawings. The system configurations can be validated with Simergy, trapping a range of input errors before running EnergyPlus and having to deal with EnergyPlus error messages. Simergy ships with a number of HVAC templates that can be used to model the baseline systems required for ASHRAE Standard 90.1 Appendix G and California Title 24 analyses and includes an extensive library structure to support the efficient use of these templates (Energyplus 2014).

2.2.1 Building facts of case study

Building shell

The typical building has five storeys with retail on the first floor and upper floors are for office use. The area of each side wall is 456 square meters, the total area of the windows is 146 square meters and the area of the roof is 1048 square meters.

As previously mentioned, one of the ways to reduce energy consumption is to improve the building shell by installing fin and overhangs on the windows. In this study the effects of external window shading have been investigated in 2 cases: (1) Windows without overhangs and side fins; (2) Windows with overhangs and side fins. Fins and overhangs have been installed on all the southern and eastern windows with the length of 1 m. Fig. 2 shows the shading device configuration. Graphic model of the building before and after this retrofit is shown in Fig. 3.

Weather

A detailed building energy simulation can only be performed if we have the necessary weather data. The weather reference model is TMY2-93815 and is selected from the Simergy model library. The basic conditions for the design of the HVAC facilities are as follows:

- Latitude: 39 degrees° North
- Altitude: 306 meters
- Dry bulb temperature (°C) maximum = 32.8, minimum = -20.6
- Dew point temperature (°C) maximum = 22.8, minimum = -23.9

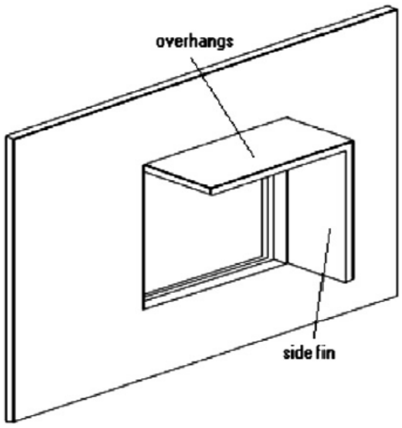
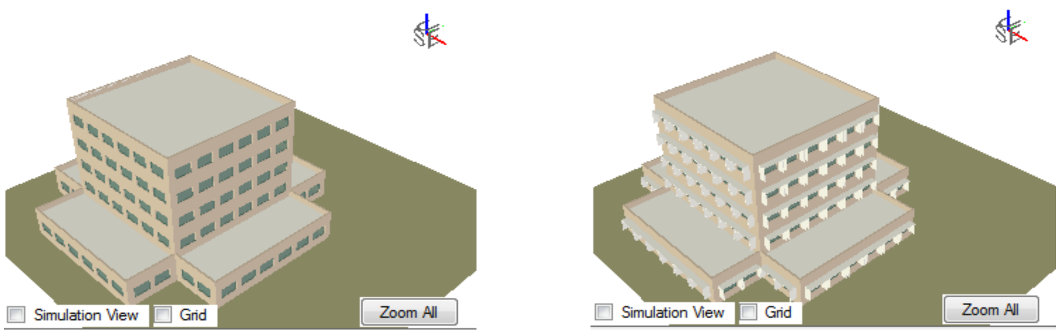


Fig. 2 Shading device configuration

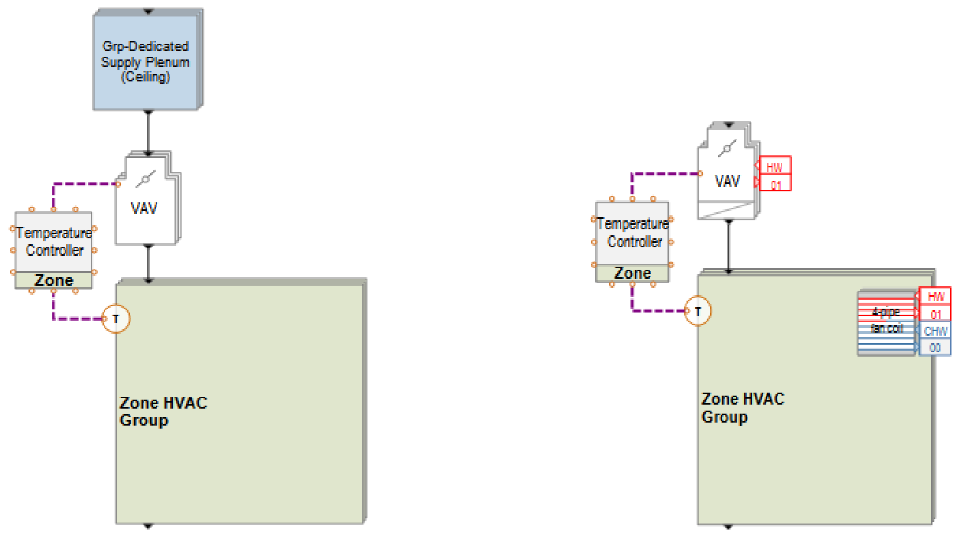


(a) Base case (b) After installation of shading devices

Fig. 3 Shading device configuration

2.2.2 HVAC systems

After determining the details of the building shell and introducing the weather data to the model, the building should be divided into zone HVAC groups. Zone grouping is based on different parts of the building where an air conditioning system has to provide service. In this typical building, two zone groups have been selected. The first zone group which is defined to supply conditioned air to the retail is a variable air volume air terminal with no reheat that is temperature controlled and supplied by a dedicated supply plenum group (AT_VAV_No-ReH_Dsupp_TC). The second zone group provides service to the office by a variable air



(a) Zone HVAC group no. 1 (b) Zone HVAC group no. 2

Fig. 4 Defined zone HVAC groups in the typical building

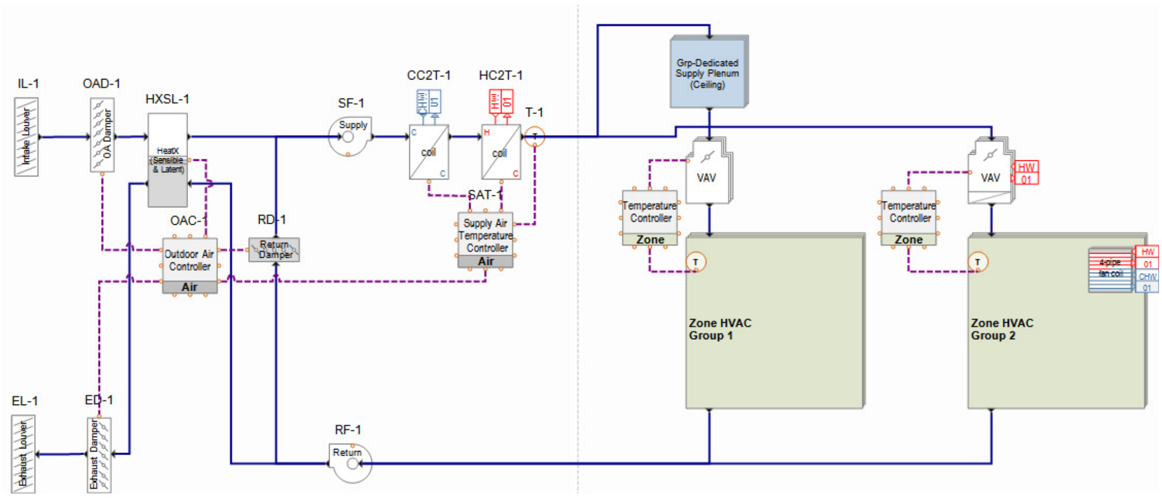


Fig. 5 Air loop block diagram

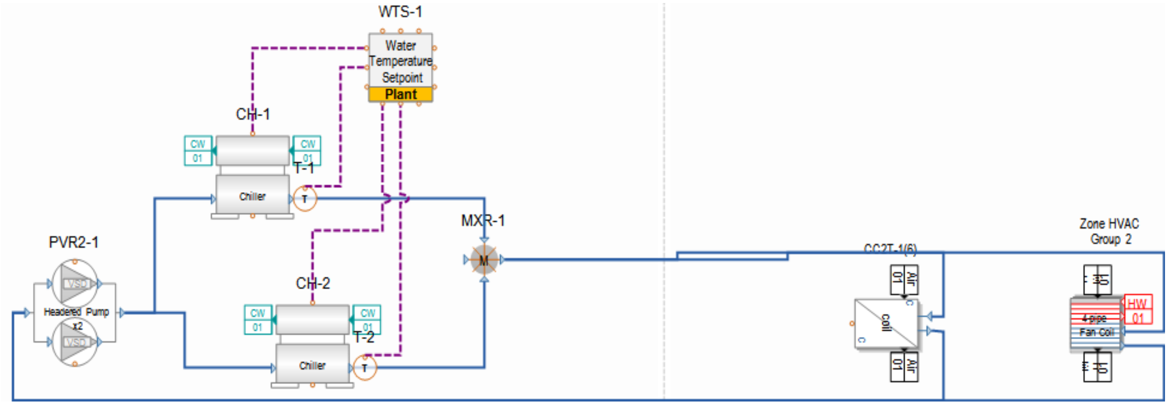


Fig. 6 Chilled water loop

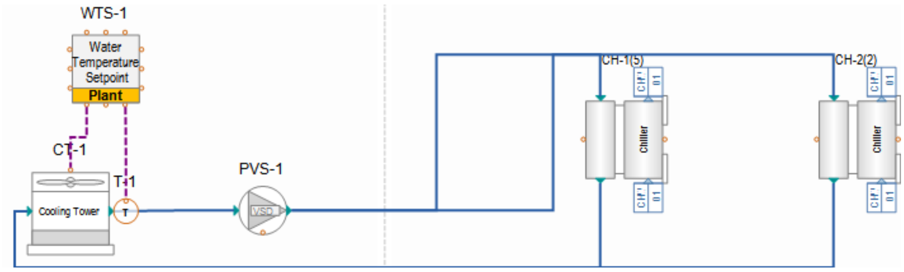


Fig. 7 Condenser loop

volume air terminal with a hot water reheat coil that is temperature controlled, a four pipe fan coil that connects to a hot water loop and chilled water loop is included as zone equipment (AT_VAV_ReH_FanCoil_TC). Figs. 4(a)-(b) show the HVAC systems for the retail and office, respectively.

After determining the zone groups of air conditioning, it is necessary to design air loops and water loops for the whole system. The air distribution portion of the HVAC system is determined by configuration of the air loop(s).

A complete air loop is composed of a supply side and a demand side. The supply side is composed of different component shapes, such as coils, pumps and fans, that are connected and contain the required properties so that the Simergy model can run effectively. In addition, controllers can be connected to a number of different components, which allows a range of control types and schemes to be introduced into the air loop (see Fig. 5).

The function of cooling towers is disposal of heat from the system to the environment. Refrigeration systems, remove the heat from the indoor air and send it to the environment through cooling towers. In the Simergy model, it is needed to define chilled water loop and condenser loop to show the interconnections between cooling towers and chillers to serve interior spaces (see Figs. 6-7).

3. Results and discussion

3.1 Electrical energy consumption before and after retrofits

Electrical power consumption by the type of use is shown in Table 1. By implementation of retrofits, a 35% reduction in energy consumption of the cooling systems could be achieved, followed by a 26% reduction in energy consumption of fans, and a 28% reduction in energy consumption of pumps. An increase in energy consumption for interior lighting is reasonable due to the adverse effects of shading on delivered solar radiation.

The total amount of electrical power saving is about 16%. According to near constant lighting share before and after the retrofit, decrease in electrical energy consumption of the air conditioning system can be calculated, showing a significant drop of 29% (from 227,836 kWh to 162,358 kWh).

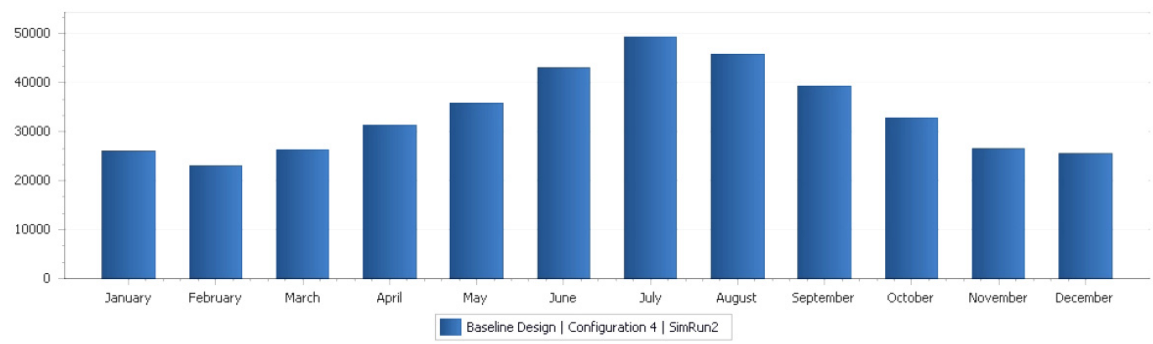
The monthly consumption of electrical energy before and after the implementation of retrofits are shown in Figs. 8-9. In July, the peak of electrical energy occurs which decreased from 49,428 kWh to 40,562 kWh. The reduction of 18% in the peak power could largely reduce the costs of electrical consumption at high levels.

3.2 Water consumption before and after retrofits

Water consumption was reduced from 1024.5 cubic meters to 500.3 cubic meters by applying the ozone treatment to the cooling tower of the building. This is about 50% water saving which makes the ozone treatment an attractive option for retrofit.

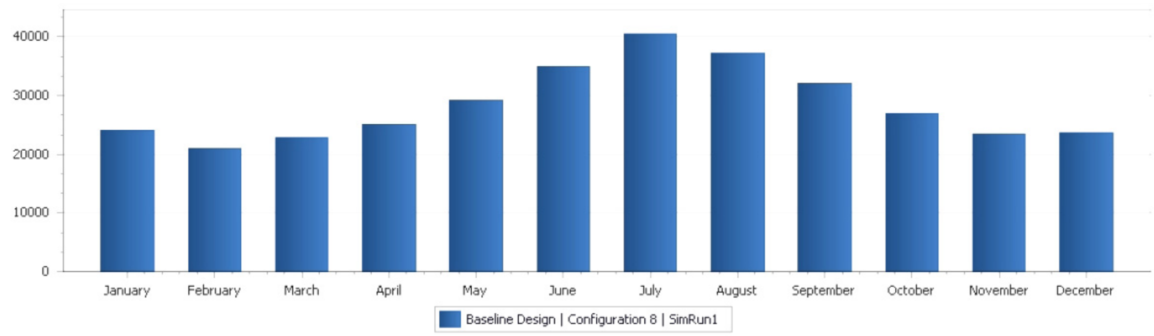
Table 1 Electrical energy consumption before and after retrofits

	Consumption (kWh)				
	Cooling	Fans	Pumps	Interior lighting	Total
Base case	49147	122886	47533	98767	405181
After retrofit	31589	90358	34136	100008	340944



	January	February	March	April	May	June	July	August	September	October	November	December	Total
Baseline Design | Configuration 4 | SimRun2	26,055	23,045	26,419	31,210	35,785	43,053	49,428	45,868	39,240	32,835	26,646	25,594	405,178

Fig. 8 Total monthly electrical consumption (kWh), Base case



	January	February	March	April	May	June	July	August	September	October	November	December	Total
Baseline Design | Configuration 8 | SimRun1	24,009	20,965	22,925	25,105	29,254	34,855	40,562	37,284	31,998	26,914	23,493	23,581	340,944

Fig. 9 Total monthly electrical consumption (kWh), After retrofit

4. Conclusions

By providing simple and effective solutions, a considerable saving in water and energy consumption in buildings can be achieved. In response to the increased importance of water and energy efficiency in the building industry and concerns of sustainability in this area, two effective solutions are offered:

(1) Use of ozone treatment for wet cooling tower.
(2) Installation of fins and overhangs on windows applied to the building shell.

Effects of these two measures taken are as follows:

- A reduction of 16% in the total electrical energy consumption.
- A reduction of 29% in electrical energy consumption used for air conditioning.
- By applying ozone treatment to the cooling towers, a reduction of 50% in water consumption of the building was achieved.

To sum up, implemention of the simple and effective measures described in this paper offers a sustainable solution to the building industry and significant water and energy conservational opportunities.

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