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The Role of Power Consumption and Type of Air Conditioner in Direct and Indirect Water Consumption

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ABSTRACT

Freshwater resources are very limited and because of the power plants, the water consumption in industry is even more than municipal. The cooling systems is a very important part of water consumption and in the past studies, it has been neglected. The analysis of cooling systems shows that, evaporative air conditioners will consume high rate of water directly and that for a house with area of 140 m^2 is about 40 m^3/month, that is about 10% of the total annual water use in typical households in an arid climate. The high power usage in compression air conditioner will also consume high water withdrawal indirectly and up to 102 m^3/month in once-through cooling system. The results of the research show that the evaporated water in evaporative air conditioners is from the municipal network and since it is being evaporated, the impact is much higher than the urban water consumption that can be collected by wastewater systems. Therefore, it is necessary to improve the previous methods to achieve the goals of sustainable development.

KEYWORDS

Water and energy, Sustainable development, Air conditioner, Indirect water consumption, Power plant.

INTRODUCTION

Research shows that human freshwater portion from the world water resources is about 2.5%. From the total fresh water consumption, about 11% is used by municipal, 19% by industrial and 70% by agriculture sectors [1]. It means that the water consumption in the industrial sector is more than municipal and the main water consumer in the industry is power plants. For producing of each kWh of electricity by a coal-fired power plant, the required water supply has been calculated and is about 1.9 L. In hydropower systems, calculations for Arizona show that for each kWh of electricity about 246 L of water must be consumed, including evaporation rates from reservoirs [2]. In another study, the average water withdrawn and consumed in natural

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gas power plants has been determined for different cooling systems and for each kWh of electricity in once-through systems, the water withdrawn is about 51.5 L and the evaporated water is about 0.228 L [3].

In 2010, about 583 Billion Cubic Meters (BCM), about 15% of the world's total water withdrawals, have been used for energy production and the total water consumption (the volume withdrawn but not returned to its source) was about 66 BCM. It is predicted that the withdrawals will increase to about 20% by 2035 and consumption will rise by a more dramatic 85%. These trends are driven by a shift towards higher efficiency power plants with more advanced cooling systems (that reduce withdrawals but increase consumption per unit of electricity produced) and by expanding biofuels production [1]. The studies show that there will be serious water issues in future for unconventional gas development and power generation by water-dependent power plants in parts of China and the United States and India. Even oil sands production in Canada and maintaining reservoir pressures to support oil output in Iraq can lead to water deficit. Energy efficiency and using new energy sources such as the wind and solar Photovoltaic (PV) contribute to a low-carbon energy future without intensifying water demands significantly but manufacturing of these devices also will use water [4, 5].

The impact of cooling systems on water and energy resource

The high energy consumption in compression air conditioners has been analysed by many researchers and to solve the energy consumption in this type of air conditioners, the evaporative air conditioner has been suggested as a green alternative [6]. The evaporative air conditioners are popular choices in arid regions. In many countries in arid regions, the direct evaporative air conditioner are being used, for example around 80% of the population in Iran (more than 13 million) and more than 10% in Australia [7]. The studies show that the average evaporated water consumption in Evaporative cooling is around 60 L/hr in Australia and it means water consumption by evaporative air conditioners is about 2-10% of the total annual water use in typical Australian households [8]. In another study by the model analysis, the average direct water consumption of an evaporative air conditioner on a typical summer day in Adelaide, Australia has been determined about 830 L/day [9]. The reports show that in some zones such as Western and South Australia their market share was around 30%. These figures are terrible for a country such as Australia that has the highest proportion, about 45%, of households using rainwater tanks. It was also reported that 22.8% of households in Western Australia used bore or well water as a source of water [10]. The comparison of the water consumption in different parts of Australia shows that in 2005 Australian households consumed on average 268 kL of water per household. In Western Australia, water consumption per household is the highest at about 468 kL while Victoria had the lowest average water consumption per household, that is about 209 kL [11]. The water saving efforts in South Australia have reduced the average values from 244 kL to around 190 kL per year in 2008 [12]. The value for Iran for a device with capacity of 5,500 m^3/h air flow is about 53 L/hr and in total about 20% of the domestic water that evaporates each year and most part of that is from groundwater that never will return to the aquifer [13]. The analysis in arid regions of Mexico shows that, the direct water consumption for an evaporative air conditioner in a 60 m^2 house with capacity of 6,800 m^3/h is about 800 L/day for 130 days as typical summer, is 104 m^3 [14]. The empirical studies in Sacramento, California show that the contribution of evaporative air conditioners in annual water usage of a household is over 10% [15]. The modelling results of an evaporative cooling system in China for a 50 m^2 building showed that the water consumed is between 60 to 72 L if the system is used for just eight hours [16].

The efficiency of direct evaporative air conditioner has been investigated through factors such as the air velocity capacity, the water temperature and the cooling temperature [17, 18]. To improve the efficiency of direct evaporative cooler, a new system has been presented with pre-cooling method with internal baffles that is indirect evaporative cooler. The results showed that the airflow rate, the inlet air humidity and temperature affect the efficiency and pre-cooling system can improve the coefficient of performance [6]. In another study, indirect evaporative cooler using sea water instead of municipal water has been investigated and the results showed that the water saving is between 3.5% to 10% and depends on the salinity of the water and for higher salinity it is more [19]. A solution for the problem of high amount of water consumption for evaporation cooling and high amount of power consumption in compression air conditioners might be using new technology such as solar water heater and solar air conditioner [20, 21].

According to the literature reviews, finding out exact relationship about water and energy and finding a new solution to decrease the water and energy consumption seems necessary. The results of the previous studies show that the performance of some parameters in evaporative air conditioners have been widely explored but there is a lack of research about direct and indirect water consumption in these devices. Since the direct and indirect water consumption by cooling and heating devices have been neglected in many studies in the past, in this study they have been considered as an innovation of this research.

The main objective of the paper is to gather an in-depth understanding of water and energy correlations and to show the importance and impact of neglected factors in previous studies such as direct and indirect water consumption by air conditioner systems. In this regard, the calculations and analysis have been done for a building in Italy, Iran and Australia.

MATERIALS AND METHODS

To calculate the direct and indirect water and power consumption by air conditioners, some factors must be determined first such as the usual air conditioner system including evaporative, compression, etc. in each region and the required capacity for the same area of house. The second stage is to calculate the direct water consumption by evaporative air conditioners and the power consumption by evaporative cooler, compression air conditioner and solar air conditioner. After determining the total power consumption, the indirect water consumption including water withdrawal and evaporation in the power plants for generating the electricity must be calculated. This calculation also depends on the type of power plant and type of cooling system. In this regard, the direct and indirect water and power consumption for air conditioners have been determined for evaporative and compression air conditioner and have been compared with solar air conditioner to find out the water and energy loss in different systems.

The water consumed by evaporative air conditioners in Australia has been shown in the Table 1.

Table 1. Water consumption in typical days in Australia by evaporative air conditioner [8]

Location	Source of data	Period requires cooling	Total daily water consumption [L/day]		Average hourly water consumption rate [L/hr]	
			9,360 [m^3/h]	16,200 [m^3/h]	9,360 [m^3/h]	16,200 [m^3/h]
Adelaide	ACAD-BSG	6:00-24:00	1,083.3	1,874.9	57.0	98.7
	ACDB	11:00-23:00	771.9	1,336.0	59.4	102.8

In Table 1, the air flow of 9,360 m^3/h is a residential house with a conditioned area of 130 m^2 and a ceiling height of 2.4 m and the air flow rate of 16,200 m^3/h for a residential house with a conditioned area of 200 m^2 and a ceiling height of 2.7 m. The water and power consumption by evaporative air conditioner that are usual in dry regions such as Australia and Iran and based on the capacity and house area have been shown in Tables 2 and 3.

Table 2. Water and power consumption in evaporative air conditioner in Iran [22, 23]

Capacity [m^3/h]	House area [m^2]	Water consumption [L/hr]	Power consumption [W]
3,500	Up to 75	35	530
4,000	Up to 110	40	590
5,500	Up to 155	53	690
7,000	Up to 200	60	890

Table 3. Water and power consumption in evaporative air conditioner in Australia [8]

Capacity [m^3/h]	House area [m^2]	Water consumption [L/hr]	Power consumption [W]
9,360	Up to 130	59.4	950
16,200	Up to 200	102.8	1,500

The power consumption in normal air conditioner (compression) that is used in Italy, has been shown in Table 4 and the power consumption in solar air conditioner has been shown in Table 5.

Table 4. Power consumption in normal air conditioner [13, 24]

Capacity [Btu]	House area [m^2]	Power consumption [W]
12,000	Up to 80	1,500
20,000	Up to 115	2,500
24,000	Up to 140	3,000

Table 5. Power consumption in solar air conditioner [25, 26]

Capacity [Btu]	House area [m^2]	Power consumption [W]
9,000	Up to 50	650
12,000	Up to 80	830
18,000	Up to 115	1,400
24,000	Up to 140	1,700

The water consumption for generation of electricity in different types of power plants and by different types of cooling systems have been presented in Table 6. The studies shows that some 30% of electricity generation involved once-through cooling, 45% recirculating cooling and just 2% dry-cooling [27]. In Table 7, the average water withdrawn and consumed per MWh of electricity in natural gas power plants have been presented.

Table 6. Water withdrawn (W) and consumed (C) for power plant cooling, in liters of water required per MWh of electricity produced [3]

Type of power plant	Once-through		Recirculating		Dry-cooling	
	W	C	W	C	W	C
Coal (conventional)	75,000-187,500	379-1,200	1,893-4,542	1,817-4,164	N/A	N/A
Natural gas (combined cycle)	28,000-75,000	76-379	568-1,071	492-1,136	0-15	0-15
Nuclear	94,000-225,000	379-1,514	3,028-9,841	2,271-3,028	N/A	N/A
Solar thermal (trough)	N/A	N/A	2,744-4,198	2,744-4,198	163-299	163-299

Table 7. Average water withdrawn (W) and consumed (C) for natural gas power plant, in m^3 of water required per MWh of electricity produced [3]

Type of power plant	Once-through		Recirculating		Dry-cooling	
	W	C	W	C	W	C
Natural gas (combined cycle)	51.5	0.228	0.455	0.814	0.0075	0.0075

RESULTS AND DISCUSSION

The water (direct and indirect) consumption for a house with area of 140 m^2 by using different types of air conditioner and the power consumption by considering natural gas power plant have been calculated and the results are as follows:

Water and power consumption in a house using evaporative air conditioner

The evaporative air conditioner is usually used nearly 24 hours a day in most of the regions in Iran and about 18 hours a day in Australia [7, 8]. In this regard, the power consumed in a month and the direct water consumed for evaporation and indirect water consumed for the power generation (by considering natural gas power plant) have been calculated and have been shown in Tables 8 and 9. The calculations are for a house with area of 140 m^2.

Table 8. Water and power consumption per month in a 140 m^2 house by using evaporative air conditioner (Iran)

Capacity [m^3/h]	Direct water consumed [L/h]	Direct water consumed [m^3/month]	Device watts [W]	Power consumed [kW]	Indirect water consumed in power plants [m^3/month]	Water withdrawal [m^3]
5,500	53	39	690	513	0.14-0.50	0.28-31

Table 9. Water and power consumption per month in a 140 m^2 house by using evaporative air conditioner (Australia)

Capacity [m^3/h]	Direct water consume [L/h]	Direct water consumed [m^3/month]	Device watts [W]	Power consumed [kW]	Indirect water consumed in power plants [m^3/month]	Water withdrawal [m^3]
9,360	59.4	44	950	707	0.19-0.69	0.39-43

Water and power consumption in a house with using compression air conditioner

The usual use of compression air conditioner is 18 hours a day. In this regard, the power consumed in a month and the water consumed for the power generation have been calculated and shown in Table 10.

Table 10. Water and power consumption per month in a 140 m^2 house by using compression air conditioner (Italy)

Capacity [Btu]	Device watts [W]	Power consumption [kW]	Indirect water consumption in power plants in a month [m^3]	Water withdrawal [m^3]
24,000	3,000	1,674	0.46-1.64	0.92-102

Water and power consumption in a house using solar air conditioner

In this part, the calculations have been done if the air conditioner is replaced by solar air conditioner. The results have been shown in Table 11.

Table 11. Water and power consumption in a 140 m^2 house by using solar air conditioner in one month

Capacity [Btu]	Device watts [W]	Power consumption [kW]	Indirect water consumption in power plants in a month [m^3]	Water withdrawal [m^3]
24,000	1,700	949	0.26-0.93	0.52-58

Comparison of water and power consumption by different systems

The comparison of water consumption, water withdrawal and power consumption in different types of air conditioners has been shown in Table 12.

Table 12. The comparisons of water and power consume in different systems for a 140 m^2 house in one month

Type	Total water consumption [m^3]	Total power consumption [kW]	Total water withdrawal [m^3] (once-through)	Total water withdrawal [m^3] (recirculating)
Evaporation air conditioner (Iran)	39.57	513.36	31.42	0.28
Evaporation air conditioner (Australia)	44.39	706.80	43.26	0.39
Compression air conditioner (Italy)	1.05	1,674.00	102.45	0.92
Solar air conditioner	0.59	948.60	58.05	0.52

The results show that the direct water consumption per month in evaporative air conditioners are 39 m^3 and 44 m^3 respectively in Iran and Australia. The water consumption in the power plants (evaporated water in cooling systems) is 0.14 m^3 in once-through system and 0.50 m^3 in recirculating system in Iran and 0.19 m^3 in once-through system and 0.69 m^3 recirculating system in Australia. These amounts are the evaporated water that cannot be used again in water cycle. At the same time, there are high amounts of water withdrawal in the power plants that are different from water evaporation in the power plants and in some cases will flow back to the water cycle like the rivers in the downstream. The total water withdrawal per month for evaporative air conditioner in Iran by considering natural gas power plant will be 0.28 m^3 in recirculating system and 31.5 m^3 in once-through system. The total water withdrawal per month for evaporative air conditioner in Australia by considering natural gas power plant will be 0.39 m^3 in recirculating system and 43 m^3 in once-through system.

For compression air conditioner, the water consumption values in the power plants are about 0.46 m^3 in once-through system and 1.64 m^3 in recirculating system. Since the power consumption of these type of air conditioners is high, the water withdrawal in the power plants are also high and the total water withdrawal per month in the power plant by considering natural gas power plant will be 0.92 m^3 in recirculating system and 102.45 m^3 in once-through system.

For solar air conditioner with lower power consumption the water consumptions in the power plants are about 0.26 m^3 in once-through system and 0.93 m^3 in recirculating system. The water withdrawal in the power plants in this type of air conditioner is lower than compression air conditioner and the total water withdrawal in the power plant per month by considering natural gas power plant will be 0.52 m^3 in recirculating system and 58.05 m^3 in once-through system.

The analysis of the water consumption in compression air conditioner shows that the indirect water consumption in the power plants is very low compared with evaporative air conditioners but the water withdrawal in gas power plants with once-through cooling systems are very high. The solar air conditioner might be the best choice because of the lower power consumption, the water consumption in the power plants is very low and water withdrawal is half of compression air conditioner.

CONCLUSIONS

In this research, since the water and energy consumption are related to each other and cooling devices use a high part of water consumption (directly and indirectly) that studies have neglected in the past, in the current study they have been analyzed. The analysis of cooling systems such as different air conditioners shows that, evaporative air conditioner will consume high rates of water directly, that is about 10% of the total annual water use in typical households in Iran, Australia and many countries in arid climate. The compression air conditioner with high power usage will consume high water withdrawal indirectly. The total water consumption (evaporated) in evaporative air conditioner for a house with area of 140 m^2 is between 40 to 44 m^3/month that is much higher than total indirect water consumption by compression air conditioner, that is about 1 m^3/month. However, since power consumption of compression air conditioner is near triple, the total water withdrawal in the power plants by using compression air conditioner is much higher than evaporative air conditioner. The value in once-through system is about 102 m^3/month. The analysis for Australia and Iran shows that one of the main reasons for high water consumption per household might be using more than 13 million units evaporative air conditioners in Iran in 2014 and about 1 million in Australia in 2010. Of course, Australia made some efforts in some regions to change evaporative air conditioners with compression air conditioner with high power usage but like some other countries such as Iran neglected the facts that raising the power consumption might lead to the rise of water consumption in the power plants itself, if the type of cooling system not being considered.

Since the water consumption in evaporative air conditioners is from the municipal network, it means that a huge amount of treated and distributed water is evaporated easily. It must be considered that the impact of this consumption that is evaporating and removed from the water cycle is much higher than the urban water consumption that can be collected by wastewater systems.

The results show that, the best possible method might be using new energy technology or using power plants with low water withdrawal, but for sustainable development, all the new methods must be examined to decrease the water and energy loss. In conclusion, by improving the previous methods the goals of sustainable development will be achieved.

SUGGESTIONS

For further analysis, it is suggested that, the heating systems are also taken into consideration and the impact of the systems on water balance in the basins. Using the case study analysis such as a basin will show more accurate results.

REFERENCES

1. Shiklomanov, I., *World Fresh Water Resources, Water in Crisis: A Guide to the World's Fresh Water Resources*, Oxford University Press, New York, USA, 1993.

2. Torcellini, P., Long, N. and Judkoff, R., Consumptive Water Use for U.S. Power Production, National Renewable Energy Laboratory Publication, NREL/CP-550-35190, 2003.
3. Macknick, J., Newmark, R., Heath, G. and Hallet, K. C., Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies: A Review of Existing Literature, Environmental Research Letters 7, 2012, https://doi.org/10.1088/1748-9326/7/4/045802
4. IEA Report, Water for Energy, is Energy becoming a thirstier Resource?, World Energy Outlook 2012, International Energy Agency (IEA), Paris, France, pp 501-528, 2014.
5. Cooley, H., Fulton, J. and Gleick, P., Water for Energy: Future Water Needs for Electricity in the Intermountain West, Pacific Institute, Oakland, USA, 2011.
6. Kabeel, A. E., Abdelgaied, M., Sathyamurthy, R. and Alexandria, A., Performance improvement of a Hybrid Air Conditioning System using the indirect evaporative Cooler with Internal Baffles as a Pre Cooling unit, *Engineering Journal*, Vol. 56, No. 4, pp 395-403, 2017, https://doi.org/10.1016/j.aej.2017.04.005
7. Pirouz, B., Using Solar Cooling/heating Air Conditioner instead of existing cooling Systems (evaporative) that used more than 200-liter Water per day (Decrease Water, Gas and Electricity consumption), National Conference on Water, Human, Earth, Isfahan, Iran, 2014.
8. Saman, W. Y. and Bruno, F., Developing a Methodology for rating evaporative Air Conditioners, Report submitted to the Australian Evaporative Air Conditioner Manufacturers and to Australian State and Commonwealth Governments, http://www.waterrating.gov.au/, [Accessed: 02-October-2017]
9. Saman, W., Bruno, F. and Liu, M., Technical Background research on Evaporative Air Conditioners and feasibility of rating their Water consumption, University of South Australia, Adelaide, Australia, 2009.
10. Australian Bureau of Statistics, Environmental Issues: Energy use and conservation, http://www.abs.gov.au/ausstats/, [Accessed: 03-October-2017]
11. Australian Bureau of Statistics, Water Account Australia 2004-05, http://abs.gov.au/AUSSTATS/, [Accessed: 03-October-2017]
12. SA Water Annual Report, South Australian Water Corporation Annual Report for the year ended in June 2008, http://www.parliament.sa.gov.au/, [Accessed: 03-October-2017]
13. Pirouz, B., Javadinejad, H., Tale Masoole, M. and Kavianpour, M. R., Practical ways to reduce Water consumption for cooling and warming Systems using new Energy, First National Conference on Intelligent Building Management Systems, Tehran, Iran, 2014.
14. Herrera1, L. C. and Azpeitia, G. G., Impact on Water consumption by Cooling Equipment in Arid Region of Mexico, 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 2006.
15. Bisbee, D., Technology Evaluation Report, Customer Advanced Technologies Program, Sacramento Municipal Utilities District, Sacramento, California, USA, 2010.
16. Zhao, X., Yang, S., Duan, Z. and Riffat, S. B., Feasibility Study of a Novel Dew Point Air Conditioning System for China building Application, *Building and Environment*, Vol. 44, No. 9, pp 1990-1999, 2009, https://doi.org/10.1016/j.buildenv.2009.02.003
17. Fouda, A. and Melikyan, Z., A simplified Model for analysis of Heat and Mass transfer in a direct Evaporative Cooler, *Applied Thermal Engineering*, Vol. 31, No. 5, pp 932-936, 2011, https://doi.org/10.1016/j.applthermaleng.2010.11.016
18. Sheng, C. and Agwu Nnanna, A. G., Empirical Correlation of cooling efficiency and Transport Phenomena of direct evaporative Cooler, *Applied Thermal Engineering*, Vol. 40, pp 48-55, 2012, https://doi.org/10.1016/j.applthermaleng.2012.01.052

19. Kabeel, A. E. and Bassuoni, M. M., A simplified experimentally tested theoretical Model to reduce Water consumption of a direct evaporative Cooler for dry climates, *International Journal of Refrigeration*, Vol. 82, pp 487-494, 2017, https://doi.org/10.1016/j.ijrefrig.2017.06.010
20. ASHRAE Handbook, HVAC Applications, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, USA, 2007.
21. Energy Efficient Strategies, Regulatory Impact Statement for Revision to the Energy Labelling Algorithms and Revised MEPs levels and Other Requirements for Air Conditioners, http://www.energyrating.gov.au/sites/new.energyrating/, [Accessed: 03-October-2017]
22. Evaporative Cooler Manual 1, Absal, model No. 4000 m^3/h Water consumption, www.tehrankala.com/4000-p-228.html, [Accessed: 05-September-2017]
23. Evaporative Cooler Manual 2, Absalmodel No. 7000 m^3/h Water consumption, www.tehrankala.com/7000-p-443.html, [Accessed: 05-September-2017]
24. Kompulasa Report, Air Conditioner Power consumption: Deciphering the Label, https://www.kompulsa.com/much-power-air-conditioners-consume/, [Accessed: 07-October-2017]
25. Solarbright Manual, Solar Air conditioner, www.solarbright.com.au/, 2016, [Accessed: 17-September-2015]
26. Dreamland Manual, Solar Air conditioner, www.indiamart.com/, 2016, [Accessed: 07-October-2017]
27. Union of Concerned Scientists, UCS EW3 Energy-Water Database V.1.3., www.ucsusa.org/ew3database, [Accessed: 09-October-2017]

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