17th Brazilian Congress of Thermal Sciences and Engineering
November 25th-28th, 2018, Águas de Lindóia, SP, Brazil

ENCIT-2018-0405
FEASIBILITY REVIEW FOR AUTOMATION AND MECHANICAL IMPROVEMENTS ON COOLING TOWERS

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Abstract. *This is a review paper that deals with the sustainability aspects for the future. It is a concern to understand how to improve outdated cooling towers to ensure the best results and competitiveness to the companies. That is an issue based on the current world situation that presses the corporations regarding the environmental conditions. The progress must be keep going without damage the environment as happened on the last industrial revolutions. Using automated control system and experimental results compared to computational aid software, it was demonstrated that great energy savings can be achieved based on the adapt of current operational conditions and schemes or with acquisition of substantial market solutions. Automation is not the only opportunity, but there are mechanical fillings and nozzles designed that can improve cooling tower effectiveness and can be used to replace outdated equipment or be used on new systems development.*

Keywords: *cooling tower, automated control, environment, sustainability, feasibility.*

1. INTRODUCTION

The proceedings of the ENCIT 2018 will be published in Adobe™ PDF format. The extended abstracts and final papers must be formatted strictly according to these instructions. The present file can be used as a template for Microsoft Word™ users. This document should be used as a formatting guide to users of other text processing softwares.

There is a strict control forecasted regarding sustainability for the next years (Bustamante et al. 2016). The energy consumption, CO_2 emissions and renewable energies usage are being tracked in order to ensure the companies' competitivity and financial aids from governments (Corrêa Da Silva und Krautz 2015; Aurangzeb und Jana 2016; Lyu et al. 2016; Chorak et al. 2017; Cutillas et al. 2017; Li et al. 2017). For example, in the Information Technology infrastructure, energy consumption has increased due a rapidly technology development in the last years and the mains focus are on cooling system (Zapater et al. 2015; Daraghmeh und Wang 2017; Fouladi et al. 2017). It is known that so many solutions of thermal cooling systems can be developed by the market engineering solution providers depending on the process characteristics (Pingye Guo et al. 2017). Most of them are not technical and/or economical feasible due high investments and low benefits based on the initial concept developed in the past, but they can be studied and improved based on new technologies to achieve best results. It is a great opportunity continuous improvement (Best und Rivera 2015).

Regarding cooling tower systems, that are the main targets on this paper, it is crucial that the major consumers must be identified and evaluated to maximize the energy savings and avoid waste of efforts in subsystems non- relevant to the conclusion. Basic, there are two different kinds of cooling tower that generated a third concept: Wet cooling tower, when the air is in direct contact with the water and Dry cooling tower, where the water is cooled in a system similar to a heat exchange (Klimanek et al. 2015; Xia et al. 2016; Zou und Gong 2016; Keshtkar 2017; Wei et al. 2017). Analyzing the benefits of both schemes, it was develop the hybrid cooling tower system, where it is used an indirect heat exchange and then a direct contact with the evaporative air (Benn et al. 2016; Taghian Dehaghani und Ahmadikia 2017).

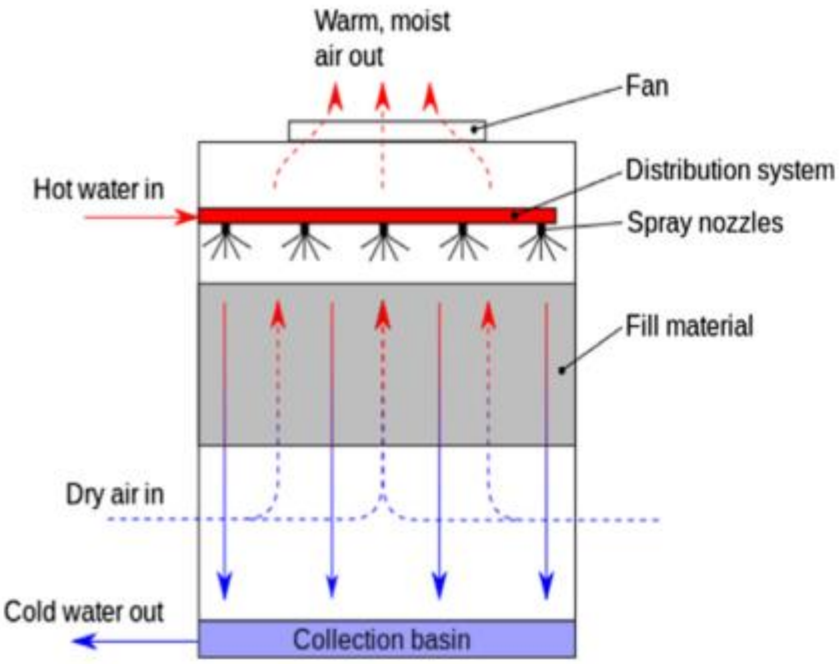

Figure 1. Cooling Tower Scheme from (Keshtkar 2017)

Based on that, it was identified that cooling and pumps networks are the most relevant parameters regarding potential benefits to energy consumption savings. Specially pump systems, there are several aspects like: interconnection ways and technologies that can rearrange the existing models to achieve optimum operational points (Korolija und Greenough 2016; Ma et al. 2017).

Historically, there was a warning regarding process automation. It was supposed to be expensive and high maintenance support to keep the system operating under operational conditions. Distributed Control Systems (DCS) are frequently in operation on production plants. It works on the process control and can manage many process steps with high reliability. Once cooling systems are an auxiliary part of the process, DCS hardware already exists and configuration is part of automation team roles, it is not expensive to optimize the operation of that systems and the results are significant considering a low investment based on the controlling strategy. In some cases, a regular ON/OFF control strategy should be enough to improve the results with a two speed cooling towers fans. In the other hand, with an investment cost, but still feasible depending on the equipment usage, a Variable Frequency Driver (VFD) should be necessary to maintains the motors durability and process optimization (Chang et al. 2015; Bornman et al. 2017).

The cooling performance should be taken as one of the main targets of the entire system and not take as just an auxiliary utilities supply. For this reason, there are many studies regarding cooling tower improvements. It can happens because the process and environmental conditions can be modified over the years and the initial concept would not be the same along the years (Singh und Das 2016).

Some numerical methods were developed to evaluate the cooling tower variables making some assumptions about the external conditions. In some situation, the numerical approaches are not accurate enough, so experimental studies were developed to check the external factors and structural design on the cooling towers performance for real results better understandings (Ning et al. 2015; Yuming Guo et al. 2017).

Besides automation control system, it is necessary a special attention to the equipment mechanical components because it will also define the equipment performance to ensure the project conditions (Cutillas et al. 2017). There's a special opportunity to improve existing cooling towers capability through modification on layout fillings (Gao et al. 2016; Martínez et al. 2016) and spray nozzle system (Alkhedhair et al. 2016; Sadafi et al. 2016).

2. MODELLING

Some results were collected as experimental outputs and other ones used computer aid simulators based on mathematical models to achieve the conclusions (He et al. 2016, 2017; Laptev und Lapteva 2016; Chen et al. 2017). In just a few studies, both methods were applied to compare the final results. There are different methodologies that can be applied to verify the cooling towers effectiveness, operational conditions, opportunities of improvements and external/internal factors influence on the equipment efficiency.

The first step to modelling a cooling tower efficiency study is to set up three critical parameters: outlet water temperature, inlet water temperature and wet bulb temperature for the region where the cooling tower will be installed. Based in that information it is possible to define de tower efficiency shown in Eq. (1) (Chang et al. 2015; Laptev und Lapteva 2016; Singla et al. 2016):

$$Efficiency: \frac{(Inlet\ water\ temperature - Outlet\ water\ temperature)}{(Inlet\ water\ temperature - Web\ bulb\ temperature)} \quad (1)$$

The difference between inlet water temperature and outlet water temperature is known as range and represents the operational condition. The difference between inlet temperature and wet bulb temperature is known as approach (Qi et al. 2016; Singla et al. 2016; Taghian Dehaghani und Ahmadikia 2017; Xie et al. 2017).

Besides the influence on cooling tower efficiency, wet bulb temperature will also set the cooling water physical size (Chang et al. 2015).

Once defined the geographical location and the physical size of the cooling tower, it Is necessary to define the pump and filling system that will work together to the weather (wet bulb temperature) and design (inlet and outlet temperatures) conditions the define the cooling tower size and efficiency (Taghian Dehaghani und Ahmadikia 2017).

Even parameter like humidity and enthalpy were considering during the thermal study to determine the optimal operational point, in fact the empirical factors were used to guarantee the results, once there is a lack of models to ensure this influence (Chang et al. 2015).

The usage of a VFD is recommended when power saving is an important factor. It can adapt the weather (it can be a season of the year or a cold/hot day) (Cutillas et al. 2017) and process (low/high load, process phase) conditions for the best results because it determines the air flow rate inside the equipment and it direct affects the effectiveness (Zhu et al. 2015). There is no clear relation between fan speed and water temperature decrease because it depends on the boundary conditions. For this reason, it should be necessary to configure a feedback PI (Proportional Integral) controller on an electronic device, such as DCS, to achieve the best results. It may consider the fan speed as manipulated variable and the outlet temperature as controlled variable. This control gives best results than ON-OFF controllers for two speed fans, that can have high switch operational conditions depending on the situations (Chang et al. 2015).

VDF are also used on cooling towers pump operations in synergy with fan speed (Ma et al. 2017). Once water flow and air inlet flow range inside the cooling tower must be controlled in order to attend the design conditions and goal the optimal energy consumption, those variables should be tested under different control conditions to give the best results (Liang et al. 2015).

Regarding mechanical devices, the nozzles are relevant components to increase the final results such as drift eliminators (Alkhedhair et al. 2016). As much contact with drift eliminators, it is expected to increase the tower effectiveness with low water loses to the environment (Ruiz et al. 2017). Computer simulation can develop and simulate an efficient device considering important factors as air flow field and their respectively turbulence. As it is an experimental situation, it is necessary to analyze a significant number of previous studies to better understanding of the nozzle behavior under certain conditions (Alkhedhair et al. 2016).

3. RESULTS

3.1 Reviewed papers results

Some results compared theoretical and practical experiments. It was possible to evaluate the best results and to propose the suitable scheme of control and mechanical design. Even the theoretical experiments do not consider some external interferences, it can be considered as an approach to the final results. The large scale based on mathematical models may not be have the same effectiveness. (Ma et al. 2015)

The results showed that the VFD operated as close as possible from the desired temperature minimizing the ON-OFF switches for regular controllers. It also demonstrated that when the system is operating in automatic conditions, it reaches the pre- conditions determined during the project phase. When there is a manual interference from operator side, the controller can run out of expected and affect the final energy consumption. Working on system with four fans and a range operation of 3,5ºC (from 34ºC to 31,5ºC) the adjustment of the temperature zone control compared to ON-OFF system, of 0,75ºC can reduce 38% of total energy consumption without increase the ON-OFF switching. This number can be higher if the temperature zone control increases (Chang et al. 2015).

VFD can also be used to control pump systems. As more cooling tower working at the same system, more potential benefits can be achieved. It is a powerful combination that can reduce energy consumption. It is necessary to control the water flow from the cooling tower combined to the fans speed to guarantee the right amount of water available to the process. It is not only the amount of water that is necessary to control the process, but the entire capacity of heat exchange on the load. It can be take in relevance the water temperature with water flow to keep the load necessity under control (Liang et al. 2015).

Regarding mechanical nozzles, there was a comparison between the experimental and the simulated values. In fact, the results were around 5%of difference between the two situations. It may occurs due the lack of some variables on the used method to calculate (Rosin-Rammler empirical equation) and the operational conditions on the test (Alkhedhair et al. 2016).

Drift eliminators are another factor that can significantly increase the system response, once they can be around 100% more efficient depending on the used material and model. The performance may vary drastically. It is significant on water savings and consequently water consumption on the system (Ruiz et al. 2017).

3.2 Experimental results

Based on the concepts reviewed during this paper, it was proposed and implemented two automated cases in a chemical plant. The cases are shown below: (for both cases there are a common pipe line that delivers the water to the cooling towers)

- Case 1: Two cooling towers working in parallel without automated control of fans (40 CV each one) and pumps (40 CV each one). There was measurement of outlet temperature and outlet water pressure. Each cooling tower has its own fan and the outlet water goes to a common pipe line where four pumps send water to the process. There was no VFD for any fan or pump;
- Case 2: Two cooling towers working in parallel without automated control of fans (20 CV each one) and pumps (20 CV for two and 40 CV for the other two). There was measurement of inlet and outlet temperature. Each cooling tower has its own fan and the outlet water goes to a common pipe line where two pumps send water to the process and two more pumps works at the bottom of the process sending the water back to the cooling towers. There was no VFD for any fan or pump.

The methodology was developed considering the following projects technical information related to each group of cooling towers independently. It is important to consider that the cooling towers design concept were based on the process thermal load and environmental conditions.

- Heat energy (Q);
- Wet bulb temperature;
- Mass flow (m);
- Specific heat of the water (c);
- Difference between inlet and outlet temperature (ΔT);
- Motors and pumps: flow and electrical power;
- Formulae (2):
  - $Q = m.c.\Delta T$ (2)

It was observed that the operators did not control the outlet water temperature based on the information that the process works better when the temperature is as low as possible (there is no official document to reinforce that information). So, the fans and pumps were always on during the whole year and all process load conditions.

Considering that the information above can be a paradigm from the process operations, it was done a task force to study some opportunities with quickly and low-cost implementation. It was studied the environmental wheatear conditions and the web bulb design temperature. The approach to the operations was related to the wet bulb temperature, saying that it was impossible to work on lower temperatures based on the cooling tower characteristics and limitations.

As results from the task force, the following actions were taken to the cooling tower efficiency improvement and energy saving (all automation actions were set up using maintenance team):

- Case 1: Install four VFD (one for each pump) to control the outlet water pressure (empirical results were collected from operations team) to reduce the water mass flow on the cooling tower. Develop an automated control for the fans based on the outlet temperature to reduce the heat energy. There was two set points defined: one for each fan. The first set point is the wet bulb temperature and the second one was set to 2ºC above the first one;
- Case 2: Develop an automated control for the fans based on the outlet temperature to reduce the heat energy. There was two set points defined: one for each fan. The first set point is the wet bulb temperature and the second one was set to 2ºC above the first one. Regarding the pumps, there was turned off two of them: one at the bottom of the plant and the other one on the outlet of the cooling tower;

In both cases, the energy savings were based on the reduction of water mass flow on the system and the reduction of the heat energy of the cooling towers. The results expected are shown below:

- Case 1:
  - reduction of 483 MWh per year (calculated)
- Case 2:
  - reduction of 338 MWh per year (calculated)

Nowadays (October 2017), the system for both cases are under implementation and will take a year to get relevant results. It is relevant that the wet bulb temperature varies a lot along the year and it is expected an impact that should be measured and it will be significant to the final result. Once there is a dry winter, it is expected a high energy saving and during the wet summer the energy saving will be lower.

4. CONCLUSION

Actually, there is a big concern regarding companies' competitiveness. Most of the time, corporations are trying to improve process conditions to guarantee the best value add for the final customer and increase the market sharing with a continuous profit increase. Besides competitiveness, there are the environmental issues in accordance with a global pressure related to environmental conditions. There is an effort from most of the nations to reduce pollutants emissions to minimize the greenhouse effect and ensure that the environmental conditions will remain properly along the years.

Based on the sustainability, the companies' continuous improvement projects should be feasible. There are countless opportunities in a plant, but this paper focused on wet cooling towers. Even inside the cooling towers universe, there are different solutions based on the project development time and implementation complexity. It has been showed that the results are significant based on the energy saving.

As most of the plants have an automated control system, like a DCS (Distributed Control System) or PLC (Programmable Logic Controller), it is not a challenge to implement an automation for the electric components for a cooling tower, like fans and pumps. Those equipment are part of the process and there is a high chance to already be available to the control. The greatest results are when the cooling tower are operating without control or on an outdated scheme. Marketing solutions like VFD operating in synergy with automation controllers can generate substantial power consumption savings based on the process phase and weather conditions. It can be adaptable to the real-time variables to achieve the best results. In addition to energy saving, automated control also increased the cooling tower reliability due the operational usage condition of electrical components.

It is important to remember that the main results were based on experimental factors and range configured on the system, once the computational simulators do not handle with weather and operational conditions with high accuracy.

Not only automation is responsible for the process improvements. There are opportunities related to the mechanical design of the cooling towers. Substitution on fillings and nozzles has demonstrated consistent results on the cooling tower efficiency reducing the difference between outlet temperature and wet bulb temperature considered on the design.

As an opportunity to further studies is to develop a mathematical simplified model that deal with boundary conditions and how it can affect the cooling towers efficiency. Once the equipment does not work all the time at the design conditions, due controlled variables (process phase, thermal load, components wear) and uncontrolled variables (weather conditions), it is a trick situation to how to optimize and measure the results after the implementations. Considering process further expansions, there is no way to be 100% sure about the cooling towers capability due the random values from the external variables.

5. REFERENCES

Alkhedhair, Abdullah et al. 2016. Numerical simulation of water spray in natural draft dry cooling towers with a new nozzle representation approach. *Applied Thermal Engineering* 98: 924–935.

Aurangzeb, Md, und Amiya K. Jana. 2016. Dividing wall column: Improving thermal efficiency, energy savings and economic performance. *Applied Thermal Engineering* 106: 1033–1041.

Benn, Steven P., Leonard M. Poplaski, Amir Faghri, und Theodore L. Bergman. 2016. Analysis of thermosyphon/heat pipe integration for feasibility of dry cooling for thermoelectric power generation. *Applied Thermal Engineering* 104: 358–374.

Best, R., und W. Rivera. 2015. A review of thermal cooling systems. *Applied Thermal Engineering* 75: 1162–1175.

Bornman, Waldo, Jaco Dirker, Deon C. Arndt, und Josua P. Meyer. 2017. Integrated energy simulation of a deep level mine cooling system through a combination of forward and first-principle models applied to system-side parameters. *Applied Thermal Engineering* 123: 1166–1180.

Bustamante, John G., Alexander S. Rattner, und Srinivas Garimella. 2016. Achieving near-water-cooled power plant performance with air-cooled condensers. *Applied Thermal Engineering* 105: 362–371.

Chang, Chun Cheng, Shyan Shu Shieh, Shi Shang Jang, Chan Wei Wu, und Ying Tsou. 2015. Energy conservation improvement and ON-OFF switch times reduction for an existing VFD-fan-based cooling tower. *Applied Energy* 154: 491–499.

Chen, Lin et al. 2017. Thermo-flow characteristics of indirect dry cooling system with elliptically arranged heat exchanger bundles around a traditional circular cooling tower. *Applied Thermal Engineering* 121: 419–430.

Chorak, Aicha, Patricia Palenzuela, Diego C?sar Alarc?n-Padilla, und Abdellatif Ben Abdellah. 2017. Experimental characterization of a multi-effect distillation system coupled to a flat plate solar collector field: Empirical correlations. *Applied Thermal Engineering* 120: 298–313.

Corrêa Da Silva, Rodrigo, und Hans Joachim Krautz. 2015. Experimental studies on heat transfer of oxy-coal combustion in a large-scale laboratory furnace. *Applied Thermal Engineering* 82: 82–97.

Cutillas, Clemente García, Javier Ruiz Ramírez, und Manuel Lucas Miralles. 2017. Optimum design and operation of an HVAC cooling tower for energy and water conservation. *Energies* 10.

Daraghmeh, Hafiz M., und Chi Chuan Wang. 2017. A review of current status of free cooling in datacenters. *Applied Thermal Engineering* 114: 1224–1239.

Fouladi, Kamran, Aaron P. Wemhoff, Luis Silva-Llanca, Kayvan Abbasi, und Alfonso Ortega. 2017. Optimization of data center cooling efficiency using reduced order flow modeling within a flow network modeling approach. *Applied Thermal Engineering* 124: 929–939.

Gao, Ming, Lei Zhang, Ni Ni Wang, Yue Tao Shi, und Feng Zhong Sun. 2016. Influence of non-uniform layout fillings on thermal performance for wet cooling tower. *Applied Thermal Engineering* 93: 549–555.

Guo, Pingye, Manchao He, Liange Zheng, und Na Zhang. 2017. A geothermal recycling system for cooling and heating in deep mines. *Applied Thermal Engineering* 116: 833–839.

Guo, Yuming, Fuli Wang, Mingxing Jia, und Shuning Zhang. 2017. Parallel hybrid model for mechanical draft counter flow wet-cooling tower. *Applied Thermal Engineering* 125: 1379–1388.

He, Suoying et al. 2016. Comparative study on the performance of natural draft dry, pre-cooled and wet cooling towers. *Applied Thermal Engineering* 99: 103–113.

He, Suoying, Yi Xu, Guanhong Zhang, Kamel Hooman, und Ming Gao. 2017. Selection of wetted media for pre-cooling of air entering natural draft dry cooling towers. *Applied Thermal Engineering* 114: 857–863.

Keshtkar, Mohammad Mehdi. 2017. Performance analysis of a counter flow wet cooling tower and selection of optimum operative condition by MCDM-TOPSIS method. *Applied Thermal Engineering* 114: 776–784.

Klimanek, Adam, Michal Cedzich, und Ryszard Bialecki. 2015. 3D CFD modeling of natural draft wet-cooling tower with flue gas injection. *Applied Thermal Engineering* 91: 824–833.

Korolija, Ivan, und Richard Greenough. 2016. Modelling the Influence of Climate on the Performance of the Organic Rankine Cycle for Industrial Waste Heat Recovery. *Energies* 9: 335.

Laptev, A. G., und E. A. Lapteva. 2016. Mathematical model and calculation of water-cooling efficiency in a film-filled cooling tower. *Thermal Engineering* 63: 724–729.

Li, Xiaoxiao, Lin Xia, Hal Gurgenci, und Zhiqiang Guan. 2017. Performance enhancement for the natural draft dry cooling tower under crosswind condition by optimizing the water distribution. *International Journal of Heat and Mass Transfer* 107: 271–280.

Liang, Wang, Yang Lu-lu, und Tian Ya-bin. 2015. Study on Energy Efficient Operation of Air-Conditioning Cooling Water System.

Lyu, Dongqiang, Fengzhong Sun, und Yuanbin Zhao. 2016. Experimental study on the air flow field in the water collecting devices. *Applied Thermal Engineering* 105: 961–970.

Ma, Huan, Fengqi Si, Yu Kong, Kangping Zhu, und Wensheng Yan. 2015. A new theoretical method for predicating the part-load performance of natural draft dry cooling towers. *Applied Thermal Engineering* 91: 1106–1115.

Ma, Jiaze, Yufei Wang, und Xiao Feng. 2017. Simultaneous optimization of pump and cooler networks in a cooling water system. *Applied Thermal Engineering* 125: 377–385.

Martínez, P. et al. 2016. Experimental study on energy performance of a split air-conditioner by using variable thickness evaporative cooling pads coupled to the condenser. *Applied Thermal Engineering* 105: 1041–1050.

Ning, Tao, Daotong Chong, Mingxiao Jia, Jinshi Wang, und Junjie Yan. 2015. Experimental investigation on the performance of wet cooling towers with defects in power plants. *Applied Thermal Engineering* 78: 228–235.

Qi, Xiaoni, Yongqi Liu, Qianjian Guo, Shanshan Yu, und Jie Yu. 2016. Performance prediction of a shower cooling tower using wavelet neural network. *Applied Thermal Engineering* 108: 475–485.

Ruiz, J., A.S. Kaiser, und M. Lucas. 2017. Experimental determination of drift and PM 10 cooling tower emissions: Influence of components and operating conditions. *Environmental Pollution* 230: 422–431.

Sadafi, M. H., Ingo Jahn, und Kamel Hooman. 2016. Nozzle arrangement effect on cooling performance of saline water spray cooling. *Applied Thermal Engineering* 105: 1061–1066.

Singh, Kuljeet, und Ranjan Das. 2016. A feedback model to predict parameters for controlling the performance of a mechanical draft cooling tower. *Applied Thermal Engineering* 105: 519–530.

Singla, Rohit K., Kuljeet Singh, und Ranjan Das. 2016. Tower characteristics correlation and parameter retrieval in wet-cooling tower with expanded wire mesh packing. *Applied Thermal Engineering* 96: 240–249.

Taghian Dehaghani, Shahed, und Hossein Ahmadikia. 2017. Retrofit of a wet cooling tower in order to reduce water and fan power consumption using a wet/dry approach. *Applied Thermal Engineering* 125: 1002–1014.

Wei, H., X. Du, L. Yang, und Y. Yang. 2017. Entransy dissipation based optimization of a large-scale dry cooling system. *Applied Thermal Engineering* 125: 254–265.

Xia, Lin et al. 2016. CFD analysis of pre-cooling water spray system in natural draft dry cooling towers. *Applied Thermal Engineering* 105: 1051–1060.

Xie, Xiaocui et al. 2017. Deciphering the thermal and hydraulic performances of closed wet cooling towers with plain, oval and longitudinal fin tubes. *Applied Thermal Engineering* 120: 203–218.

Zapater, Marina et al. 2015. Leakage-Aware Cooling Management for Improving Server Energy Efficiency. *IEEE Transactions on Parallel and Distributed Systems* 26: 2764–2777.

Zhu, Na, Pingfang Hu, Yu Lei, Zhangning Jiang, und Fei Lei. 2015. Numerical study on ground source heat pump integrated with phase change material cooling storage system in office building. *Applied Thermal Engineering* 87: 615–623.

Zou, Zheng, und Hengxiang Gong. 2016. Numerical analysis of solar enhanced natural draft dry cooling tower configuration. *Applied Thermal Engineering* 94: 697–705.