Arinda P. RACHMAN [1],
Vojtěch ZAVŘEL [1,2],
J.Ignacio TORRENS [1,3],
Jan L.M. HENSEN [1]

[1] Building performance group, Dept. of Built Environment, Eindhoven University of Technology
[2] CTU in Prague, Faculty of Mechanical Engineering, Dept. of Environmental Engineering
[3] Building Technologies division, TECNALIA

Reviewer
Ing. Pavel Herout

A Simulation-based Assessment of Humidity Treatment in Data Centre Cooling Systems with Air-Side Economisers

Simulační posouzení úpravy vlhkosti v systémech chlazení data center s ekonomizérem na straně vzduchu

The increasing digitalisation of data is resulting in the need for ever greater computational capacity, which in turn leads to the increasing energy consumption in data centres. A large percentage of this energy use arises from the need to mechanically remove an enormous amount of heat from the data centre environment. In fact, in current practice, the mechanical infrastructure (especially cooling systems) of the data centre accounts for up to half of the overall energy consumption. To reduce the energy consumption of the mechanical infrastructure, several economisation methods are commonly implemented in cooling systems, one of which is the application of a direct air-side economiser addressed in the current research. The use of an air-side economiser has been shown to lead to major savings of the cooling electricity demand, and, as such, it has been widely used as a necessary addition to conventional cooling systems. This study analyses the energy breakdown of data centre cooling systems that include an air-side economiser in order to determine which components within the system are responsible for the major energy consumption. This study investigates, via a computational simulation, the impact of the use of a conventional cooling system and a system with an air-side economiser on total energy demand in three locations representing different climate regions in Europe. The study is especially focused on the energy demand related to the humidity treatment in the data rooms, since the effect is rarely considered in the overall DC energy balance. The results demonstrate, as expected, that the air-side economiser can yield major savings of around 62.5% to 78.7%, depending on the given climate regions. However, the key result of this study is that the humidity treatment necessary for the direct air-side economiser system may consume up to 34.8% of the total energy demand of the cooling system with the air-side economiser.
Keywords: *data centre's cooling system, air-side economiser, humidity, energy analysis, energy simulation, simulation-based assessment*

Narůst digitalizace dat má za výsledek potřebu stále vyšší výpočetní kapacity, která má za důsledek významný růst globální energetické spotřeby data center. Značné procento z celkové energetické spotřeby data center je přičítáno chlazení, které mechanicky odebírá enormní množství tepla disipováno výpočetní technikou uskladněnou v prostoru data centra. V současné době, mechanická infrastruktura data center (především systémy chlazení) spotřebovávají až polovinu celkové energie data center. Několik různých metod ekonomizace provozu chladicího systému je v současné praxi k dispozici, a jednou z nich je využití přímého volného chlazení na straně vzduchu, která je zkoumána v tomto článku. Využití volného chlazení již prokázalo, že vede ke značným úsporám a je často běžnou součástí systémů chlazení v data centrech. Tato studie analyzuje rozdělení energetické spotřeby chladicího systému datacenter, jehož součástí je také zařízení pro volné chlazení, tak aby bylo umožněno vyhodnotit spotřebu energie jednotlivých částí systémů a zkoumá za pomocí numerických simulací zmíněné rozložení energie pro systém s a bez ekonomizace pro tři lokality reprezentující různé klimatické zóny v Evropě. Tato studie se zvláště zaměřuje na energetickou spotřebu úpravy vlhkosti v data centrech, protože tento jev je jen zřídka brán v úvahu při celkové energetické bilanci data center. Výsledky demonstrují očekávanou energetickou úsporu při využití volného chlazení na straně vzduchu, a to v rozmezí 62.5 % až 78.7 % v závislosti na dané klimatické zóně. Avšak, hlavním výsledek této studie je, že zařízení na úpravu vlhkosti, která je u přímého volného chlazení na straně vzduchu nezbytná, mohou spotřebovat až 34.8 % z celkové spotřeby systému chlazení s tímto ekonomizérem.
Klíčová slova: *chlazení data center, volné chlazení na straně vzduchu, vlhkost, energetická analýze, energetická simulace, posouzení na základě simulace*

INTRODUCTION

The energy consumption of data centres has increased in line with the recent demand for cloud computing. Overall, data centres consumed nearly 1.5% of the total world electricity consumption in 2005 [1]. According to the Natural Resources Defense Council (NRDC) findings, U.S. data centers consumed around 91 terawatt-hours (TWh) of electricity in 2013 and this figure is projected to increase to roughly 140 TWh annually by 2020 [2]. As such, there is significant potential and a great need to reduce the energy consumption and the associated climate-changing pollution of data centres.

In general, power distribution consumed by systems in the data centre can be simply divided into two categories covering the IT equipment and data centre infrastructure, which includes the electrical, mechanical and auxiliary systems. Considering the overall power consumption of the conventional data centre infrastructure, up to half of its total energy is typically consumed by the mechanical systems [3], [4]. The cooling systems commonly consume around 40% of the total data room consumption [5], [6]. Therefore, reducing the power consumption of the cooling systems is considered a high priority in the operation of a data centre.

There are several energy efficiency measures and economisation methods to minimise the power consumption of the data centre's cooling system. Aside from increasing the setpoint of air supply temperature or improving the air distribution within the DC, utilising outside air for free cooling can lead to a major reduction in the total electricity demand [1], [2], [7]. One of the economisation methods is an air-side economiser, which can benefit greatly from the ambient temperatures below 18 to 21°C. Nowadays, economisers are integrated into the configuration of data centre cooling systems as an energy efficiency measure. These systems can be understood as the new benchmark, and their implementation is becoming widespread. In anticipation of this widespread implementation, this research represents an attempt to provide a detailed energy breakdown of such a cooling system as well as providing an initial screening for possible future in-depth research of the individual components.

The current research is aimed at the humidity treatment in the system with the direct air-side economiser. Considering these types of systems, when the outside air enters the critical environment of the data room, the tight humidity treatment is necessary to satisfy the strict requirements for the IT operational conditions given by the standards [8]. Indeed, the implementation of a direct air-side economiser results in the need of a tightly controlled indoor humidity level to prevent the data centre's space from negative effects such as condensation on the equipment when the outside air is too moist, or excess static electricity when it is too dry [4], [5].

The key focus area of this research is the energy demand related with the humidity treatment, which is often neglected during the calculation of the total energy demand. Indeed, in conventional configurations, where the indoor air is circulated and most of the cooling power demand is related to the energy-hungry refrigeration cycle, the energy demand related to the humidity treatment is relatively low. However, by introducing outside air to the data centre's environment in order to bypass the refrigeration throughout the year, the energy break-down will change, which means that it is unwise to continue to neglect the energy demand for the humidity treatment.

RESEARCH QUESTION AND METHODOLOGY

To reach the objective mentioned in the previous section, the following research question was stated and will be answered: *What is the impact of the humidity treatment on the total energy consumption of the cooling system with the air-side economiser in data centres?*

The current research was conducted based on the methodological steps described below in order to quantify the impact of the humidity treatment on the total energy consumption.

- ❑ A literature study was performed on the related studies regarding data centres' cooling systems and economisers.
- ❑ A heuristic model of the data centre was developed in Matlab [11] to briefly understand the change in energy breakdown. Specifically, the model was built based on the reference mid-sized data centre [8]. The model consists of two cooling typologies; conventional cooling systems and a system with an air-side economiser.
- ❑ The simulation of the data centre model was executed for various climatic regions within Europe and for constant IT utilisation. The simulation focuses on the cooling energy demand broken down into the individual components. In order to assess the energy demand throughout the year. The simulation timestep of 1hour was selected.
- ❑ The simulation results were evaluated for each climate by the selected key performance indicators. These are the annual energy use of the individual components and the power usage effectiveness (PUE) [12].

DATA CENTRE AND SYSTEMS REPRESENTATION

Data centre model

The data centre (DC) model used in this research represents a typical mid-sized DC and it is based on the description of a case study of an IBM test facility located in Poughkeepsie, New York [8]. This case study provides rich information with a sufficient level of detail, in a field (i.e., commercial DCs) with documentation scarcely available, generally due to confidentiality issues. The facility houses 135 servers, has a floor area of 693.68 m^2 and layout dimensions of 23.3×29.9 m. The servers were arranged based on a hot and cold aisle arrangement without separation. A U-value of 0.24 W/m^{2}K was assumed for the building envelope.

The performance of the DC is represented by variables such as power consumption, airflow, and air temperature in the IT environment. According to the available specification of the case-study, the overall power consumption of the IT infrastructure is 1098.2 kW. This electrical power is assumed to be converted to heat, which is dissipated in the data room space. This enormous heat gain must be mechanically removed from the space to ensure the required operational conditions of the IT equipment.

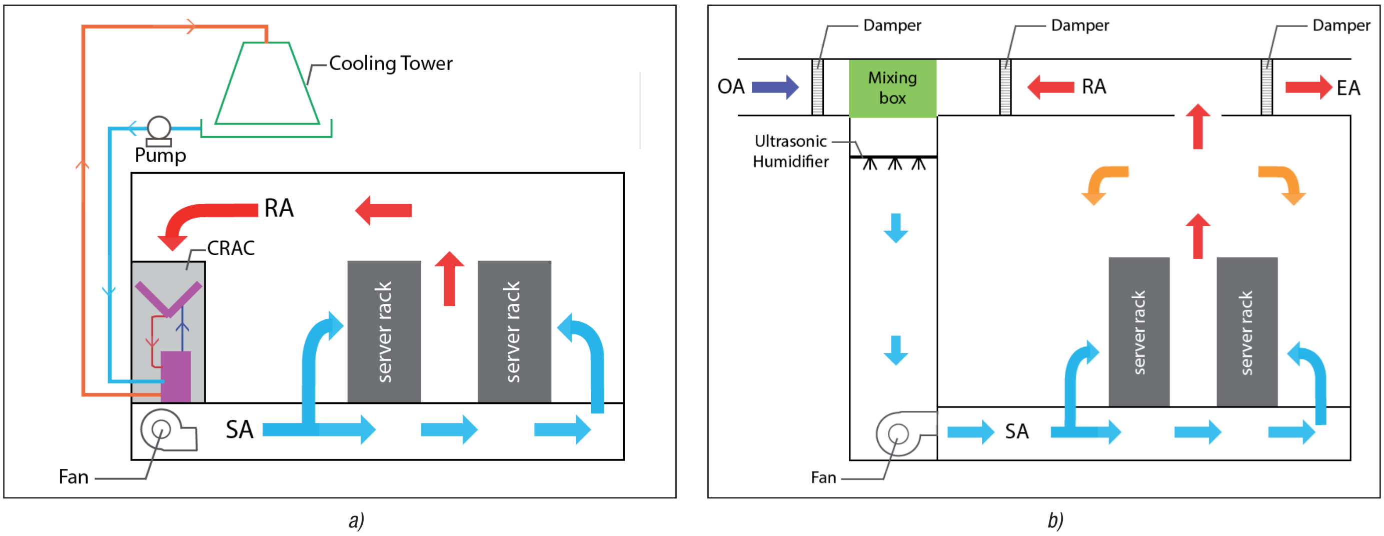

Fig. 1 schematic diagram of: (a) a conventional cooling system and (b) a cooling system with an air-side economiser

Therefore, two cooling systems are assumed in this study: (a) a cooling system with a computer room air conditioner (CRAC) unit using a refrigeration circuit, which represents the conventional approach, and (b) a cooling system with an air-side economiser, which represents the new generation of DC cooling systems. These two systems are schematically depicted in Fig. 1.

Computer Room Air Conditioner (CRAC)

Generally, a computer room air conditioner (CRAC) unit is used to reduce the return air temperature by removing the dissipated heat from the IT environment. The indoor environment of the modelled data centre was assumed to fall within the recommended temperature range. The recommended range according to data centre's thermal guidelines of ASHRAE TC 9.9 [13] is highlighted in yellow in Fig. 2, which also includes the allowable ranges in which the inlet server temperature may fall for short periods of time [14].

Although it is allowed to set a higher server inlet temperature, the appropriate indoor environment should be carefully controlled for data centres without a hot and cold aisle separation, so-called containment. When the sum of the airflow throughout the servers is higher than supply airflow of the cooling system, unseparated aisles can potentially cause hot air recirculation into the cold aisle resulting in higher server inlet temperatures [15]. Since the hot and cold aisle in this data centre model was mixed, the modelled cooling systems were operated with a setpoint of the air supply with dry-bulb and dew-point temperatures of 21°C and 11°C, respectively.

The specification of the CRAC unit used in the model is given in Table 1 The amount of airflow $\dot{m}_{air}$ needed to remove the heat from the IT room can be calculated using Equation (1).

$$\dot{m}_{air} = \frac{\dot{Q}_{overall}}{c_{p,air}\,\Delta T} \qquad (1)$$

where $\dot{Q}_{overall}$ is the total heat to be removed from the data room space, ΔT is the temperature difference between the inlet and outlet air from CRAC unit, $c_{p,air}$ is the specific heat capacity of the dry air.

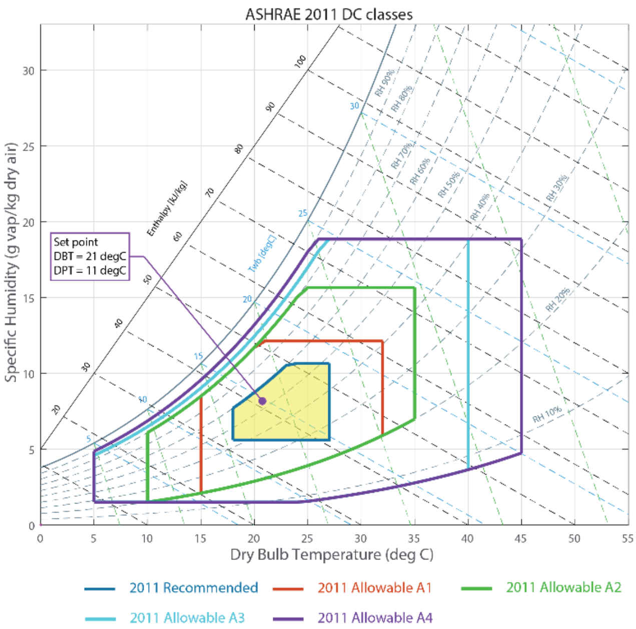

Fig. 2 ASHRAE proposed thermal condition for data centres

Tab. 1 CRAC unit model specification

Configuration: Down-flow Down	
Refrigerant	R410A
Net sensible cooling capacity	46.1 kW
Fan power input	2.1 kW
Unit power input	12.79 kW
COP	3.1
Air pressure loss (underfloor air distribution)	20 Pa
Maximum air flow	14500 m³/h
Condenser Section	
Water inlet temperature	30 °C
Condensing temperature	45 °C
Maximum water flow	1.31 L/s

Air-side economiser

The air-side economiser is used to reduce the cooling system related energy consumption and cost by utilising the outside air to reject the heat from the IT environment [16]. The outside air (OA) is brought into the building and distributed via a series of dampers and fans. The servers ingest the cool air, transfer the heat, and expel the hot air from the room. Rather than being recirculated and cooled, the exhaust air (EA) is simply directed outside. If the outside air is particularly cold, the economiser may mix the outside air (OA) and the return air (RA), ensuring that the air supply (SA) temperature falls within the desired range for the equipment. The ratio of the outside and the return air used in the mixing process was estimated using Equations (2) and (3).

$$m_{RA} = \frac{m_{SA}\left(t_{SA} - t_{OA}\right)}{t_{RA} - t_{OA}} \qquad (2)$$

$$m_{OA} = m_{SA} - m_{RA} \qquad (3)$$

The air-side economiser model that was used in this study is schematically illustrated in Figure 1b. In this model, the economiser is equipped with an ultrasonic humidifier. The humidifier was used to maintain the recommended air supply moisture level when the outside air moisture level was low. In addition, dampers were used to control the amount of the outside air and the return air that was mixed in the mixing box.

Humidifier

The humidifier is used to maintain the humidity level of supply air as recommended in the ASHRAE TC 9.9 standard. In this study, an ultrasonic humidifier was chosen as the humidifier model, alternatively a high pressure fog system can be an option. The device was activated when the supply air humidity was lower than the ASHRAE recommended range for the data centre. The power consumption of the humidifier was estimated using Equations (4) and (5).

$$P_{uh} = e_{ult}\,\dot{m}_{w,uh} \qquad (4)$$

$$\dot{m}_{w,uh} = \frac{\dot{m}_{w,hum}}{\eta_{de-ionised}} \qquad (5)$$

It was assumed that the de-ionising effectiveness ($\eta_{de\text{-}ionised}$) was 0.75, while the electricity consumption per unit mass of water (e_{ult}) was defined as 0.053 kW/kg [17].

Cooling tower

In this study, cooling towers were used to reject the heat from the IT room to the outside environment by spraying warm condenser (cooling) water onto the filler at the top of the towers. The water spreads out, and some of it evaporates away as it drips through the sponge-like material [18]. The evaporation reduces the temperature of the remaining water, which is collected at the bottom of the towers. The cooling water is pumped back via pipes to the CRAC units' condenser.

The heat removed by the cooling tower was calculated using Equations (6) and (7). Furthermore, Eq. (8) was used to determine the total absorbed heat from the CRAC units' condenser.

$$Q_{CT} = \eta m_a \rho_a \left(h_{swi} - h_{ai}\right) \tag{6}$$

$$\eta = \frac{T_{wi} - T_{wo}}{T_{wi} - T_{wb,ai}} \tag{7}$$

$$Q_{condenser} = m_w \rho_w c_{p,w} \left(T_{wi} - T_{wo}\right) \tag{8}$$

Since air is needed to reduce the water temperature through an evaporation process, the cooling tower is equipped with fans to supply the air. The power input of the fan is dependent on the amount of airflow, as described in Equation (12). In order to calculate the power input of the fan, the airflow needs to be calculated using Equation (9). In this study, the amount of released heat by the cooling tower was assumed to be 20% higher than the absorbed heat from the condenser.

$$m_a = \frac{1.2 \cdot Q_{condenser}}{\eta \rho_a \left(h_{swi} - h_{ai}\right)} \tag{9}$$

Pump and fan

A pump was used to deliver the cooling water from the cooling towers to the CRAC units, and the volume of the water was assumed to be constant. Equations (10) and (11) were used to calculate the power consumption of the pump model [3], [10], [11]. In this study, the pump efficiency (η_{pump}) was assumed to be 60%.

$$P_{pump} = \frac{\dot{m}_{w,pump} \Delta p_{pump}}{\rho_w \eta_{pump}} \tag{10}$$

where,

$$\dot{m}_{w,pump} = \frac{\dot{Q}_{overall}}{c_{p,w}} \Delta T_{w,pump} \tag{11}$$

The fans are modelled with the assumption of a constant airflow rate. This control simplification is made because the total dissipated heat from the IT equipment was also assumed to be constant. The fan power consumption can be calculated using Equation (12) where the fan efficiency (η_{fan}) was assumed to be 60% [3], [10], [12].

$$P_{fan} = \frac{\dot{V}_{RA} \sum \Delta p}{\eta_{fan}} \tag{12}$$

ENERGY SIMULATION DEFINITION

Geographical location and climate properties

This study estimated the impact of the humidity conditions on the overall and individual energy consumption of the air-side economiser. To analyse this impact, several locations from the north to the south of Europe with different climate conditions were used in the simulations. The tested locations are described in Table 2.

Tab. 2 Climate information of the tested locations

City	Location		Design temperature [°C]		Climate type	Köppen classification
	Latitude	Longitude	Dry bulb	Wet bulb		
Helsinki, FI	60.17° N	24.94° E	22.8	18.0	Humid Continental Climate	Dfb
Groningen, NL	53.22° N	6.56° E	24.2	19.8	Temperate Oceanic Climate	Cfb
Rome, ITA	41.90° N	12.49° E	27.9	25.4	Mediterranean Climate	Csa

Case 1: Conventional cooling system

The conventional cooling system, shown in Figure 1, cooled the return air and supplied the cooled air to the servers. In this case, the refrigeration unit was used continuously to maintain the air condition inside the IT environment. In this study, it was assumed that the return air was 33 °C and that the CRAC units would cool the return air to 21°C before supplying it to the server racks.

In this model, the amount of make-up water that was used to replace the evaporated water was not taken into consideration. As such, the energy input for the make-up water pump was not included in the simulation. The efficiency of the cooling tower was determined based on the design temperature of each location, as given in Table 2.

Case 2: Direct air-side economiser system

In this case, the air-side economiser system with an ultrasonic humidifier was used for the data centre cooling system. In order to meet the range as recommended by ASHRAE TC 9.9, the dry bulb temperature (DBT) of the supply air was set to 21°C with the dew point temperature was set at 11.1°C. The operation of this system was divided into four modes, depending on the outdoor air condition. As illustrated in Figure 3, the mode of the conventional refrigeration of the circulated indoor air was utilised when the outdoor air dry-bulb and dew point temperatures were higher than the recommended temperature range. Otherwise, the air economiser is utilised in the following modes: the direct use of the outside air, the mixing mode with the return air to heat up the supply air, and the mixing mode with the return air plus additional humidification.

According to the data centre model, the dissipated heat of servers and lighting was 1098.2 kW. Therefore, in order to remove the heat to the outside environment, 24 CRAC units were required with a total cooling capacity of 1106.4 kW. Since the amount of heat losses through the building envelope is negligible (less than 1%) in context of the enormous amount of dissipated heat from the IT equipment, the total mass flow of the air required to cool down the IT environment can be calculated using Equation (1) described in the previous section. Assuming the temperature difference between the return and air supply (ΔT) was 12 °C, the required airflow to remove the dissipated heat and lighting was 273×10^3 m^3/h. The economiser was active when the outside air dry-bulb temperature was equal to or lower than the setpoint temperature. The outside air was directly introduced to the IT environment when its dry bulb temperature was equal to the set point, and its dew point temperature was within the recommended range given by the ASHRAE standard for data centres.

Otherwise, when the outdoor air dry-bulb temperature was lower than the set point (21 °C), the outside air was mixed with the return air until the set point condition was reached. However, when the dew point temperature of the mixed air was within the allowable range, the mixed air was supplied to the IT environment without being humidified. In contrast, when the dew point temperature of the mixed air was lower than the setpoint (T_{dp} < 11.1°C), the humidifier operated to maintain the humidity of the air. The air was supplied when the set point was reached.

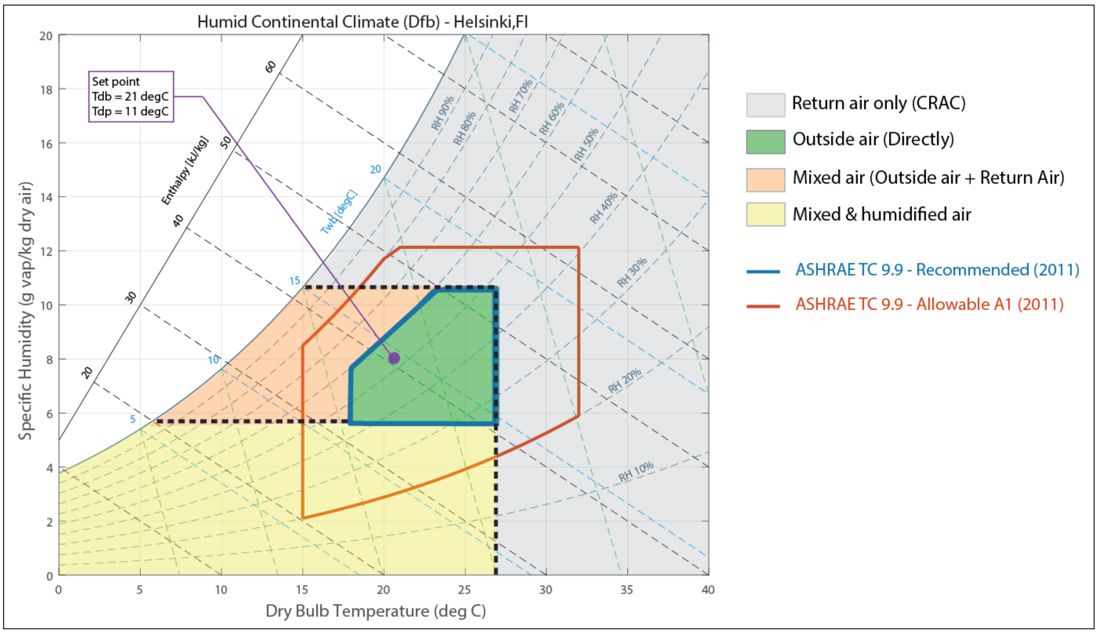

Fig. 3 Air-side economiser operation scheme

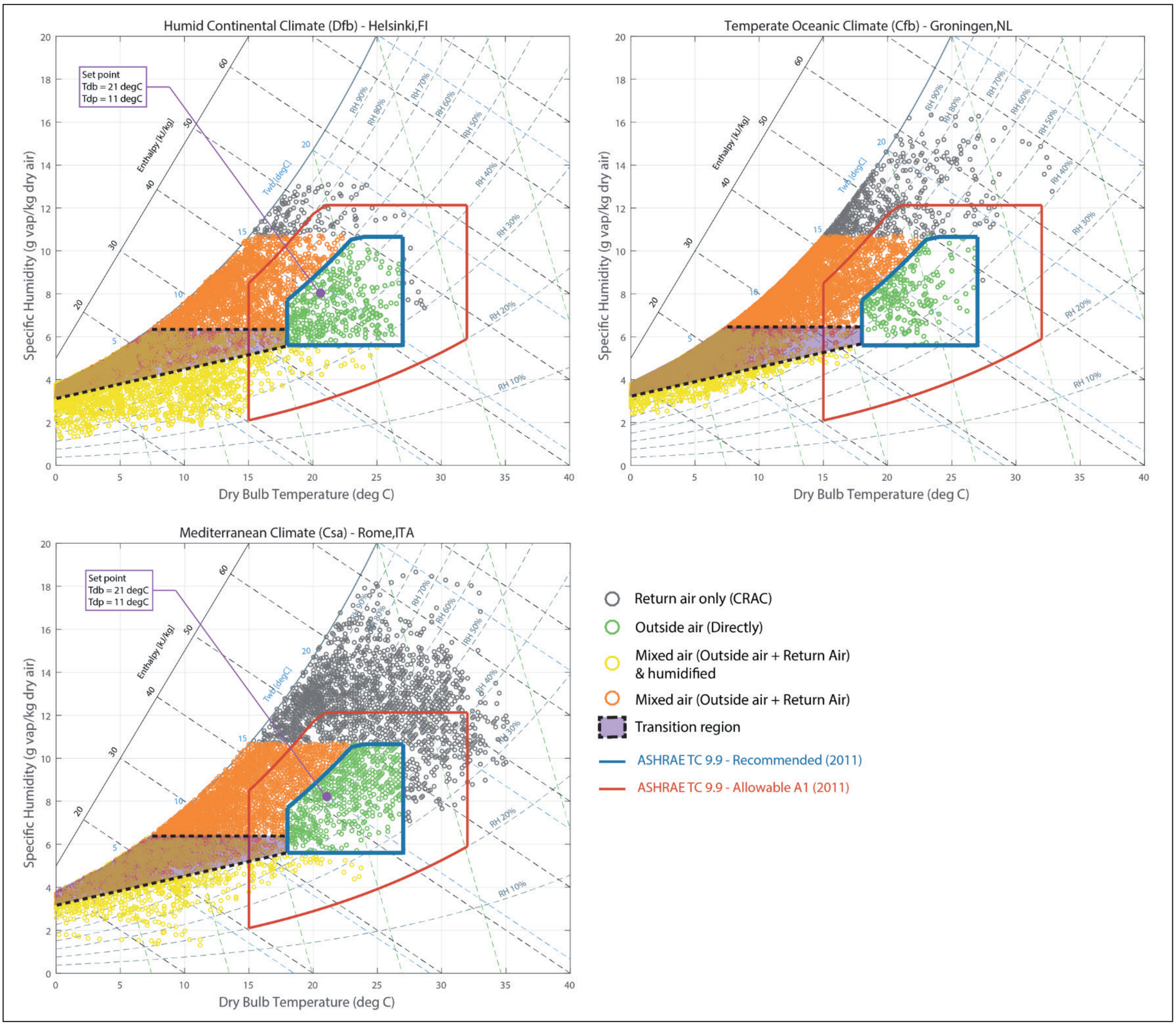

Fig. 4 Comparison of the weather conditions for each tested location

RESULTS AND DISCUSSION

The total annual energy saving potential of the tested cooling systems was calculated for three different locations to address various climatic zones within Europe. Fig. 4 shows the psychometric charts for the outside air for each tested geographical location in this study. This figure is used to analyse the potential of the air-side economiser in each operational mode described above. The theoretical straight boundary shown in Fig. 3 between mixing modes with and without additional humidification was not observed in dynamic simulations. Instead, a transient region was found between these two modes. In this area, which is highlighted in purple, the outside air can be conditioned in two different ways, depending on the return air conditions. A high moisture content of the return air contributes to a higher moisture content of the mixed air. Thus, humidification was not necessary for these scenarios. On the other hand, when the moisture content of the return air was not rich enough, a humidification process was needed to maintain the humidity level of the mixed air before it was supplied to the IT environment.

Based on the information in Fig. 5, the location with a Humid Continental Climate profile (Dfb) represented by Helsinki has the highest potential to utilise the air-side economiser compared to the other tested locations. However, the graph shows that the humidity conditions of the outside air in this location were predominantly lower compared to the other locations. Consequently, the operational time of the mixing mode with humidification was higher for this location. On the contrary, the other tested climatic zones, which are represented by Groningen and Rome, have a higher number of operational hours of the air-side economiser in modes of direct use and mixing without the need of additional humidification. Therefore, the results lead to the lower energy consumption of the humidifier in these locations.

Tab. 3 PUE and Annual total electricity use for given locations

	scenario 1 Baseline	scenario 2 Helsinki	scenario 3 Groningen	scenario 4 Rome
PUE	1.34	1.07	1.07	1.12
Total electricity use (GWh)	12.88	10.29	10.31	10.80
Total electricity use by mechanical systems (GWh)	3.26	0.67	0.69	1.18

In order to analyse the energy consumption, Fig. 6 demonstrates the energy consumption of each cooling system, which was obtained from the simulations and their *PUE* values. Meanwhile, Fig. 7 shows the proportion of the energy consumed by each component in the system. The simulation results of scenario 1 (baseline) only show the energy consumption of the conventional cooling system with refrigeration. In our study, this cooling system performed similarly regardless of the geographical location. As shown in Tab. 3, The simulated results were in the range of 3.24 to 3.26 GWh, resulting in a PUE of 1.34 for all locations. Such a small range for each location is the result of selecting a simplified heuristic modelling method focused mainly on modelling the air-side economiser. A slightly higher variance could be reached by implementing a dynamic coefficient of performance of the refrigeration cycle. However, the simplified model gives sufficient information to generate a common baseline for the study of the air-side economiser.

As depicted in Fig. 7, generally, 96% of the total energy of the conventional cooling system was used by the refrigeration units. The cooling tower took 3% of the total energy used by the conventional cooling systems, while the rest was used for pumping the cooling water and for the fans.

The second design (Case 2), where the air-side economizer is implemented, led to reduction of the total energy consumption by 73.2% on average in comparison with the baseline. The reduction of the total energy consumption resulted in the improvement of the PUE of each location to 1.07, 1.07, and 1.12 for the Humid Continental Climate (Dfb), the Temperate Oceanic Climate (Cfb) and the Mediterranean Climate (Csa), respectively. The most significant saving, which was 78.7%, was reached when the economiser was utilised in a location with a Humid Continental Climate (Dfb), represented by Helsinki. It is

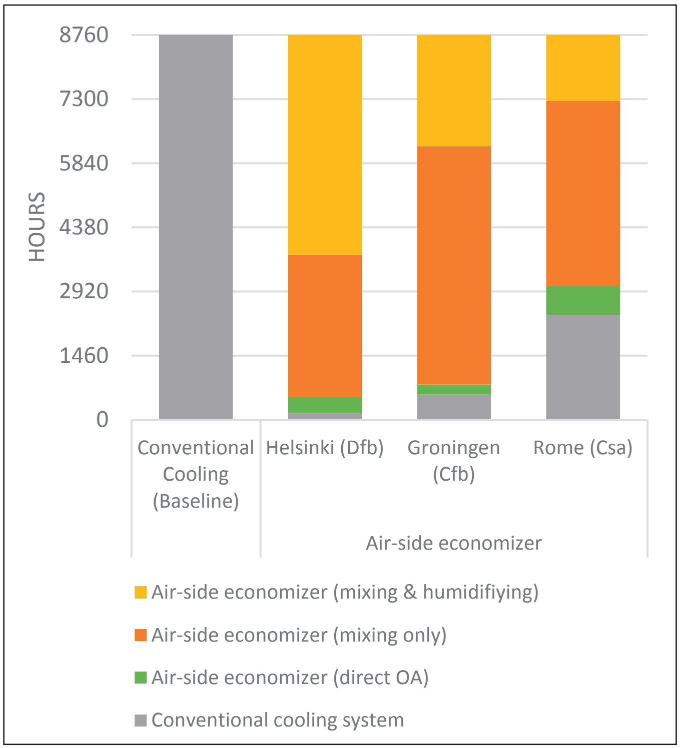

Fig. 5 Annual operating hours of the cooling system models

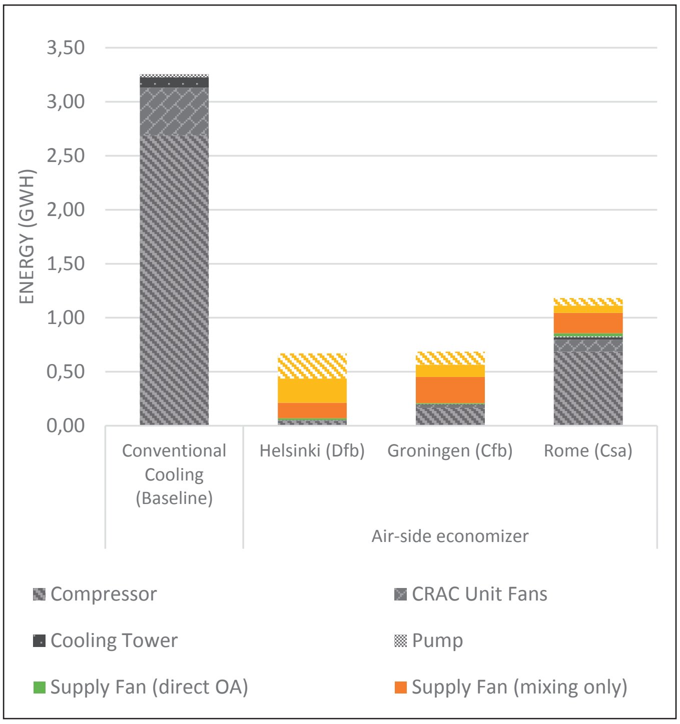

Fig. 6 Annual individual equipment energy consumption of the cooling systems in given locations

worth noting that the energy demand of the humidity treatment in this scenario reached 34.8% of the total energy use of the cooling system. Therefore, the Temperate Oceanic Climate (Cfb), represented by Groningen, with a lower proportion of humidification hours offers almost the equivalent economisation potential, even though the utilisation of the refrigeration unit is higher. The relative energy savings for the Temperate Oceanic Climate was 78.4%. The proportion of humidifier energy use of the total energy use was 16%. The simulation results demonstrate that the air-side economiser is able to significantly reduce the annual energy consumption of the cooling system by 73.2% on average. The savings vary from 62.5% to 78.7%, depending on the given climatic region. The resulting major savings were expected and similar figures are provided by the cooling unit manufacturer, e.g., [22], which states a range of 70% to 95% for similar conditions. However, this study was specifically focused on the impact of the humidity treatment within the air-side economiser on the total energy demand, which is likely neglected in other studies.

Considering the effects of the location and climate condition, the utilisation time of the air-side economiser, as depicted in Fig. 5, decreases as the latitude decreases. The temperature of the outside air and its specific humidity increase as the location nears the equator. Due to this reason, the number of hours when the outside air condition lies below the set point temperature was decreased, which resulted in in the higher utilisation time for the conventional cooling system. Among the tested locations, the largest annual energy consumption of the conventional cooling system was found in a location with a Mediterranean Climate (Csa), which was represented by Rome. In this location, the conventional cooling system consumed 70% of the total annual energy consumption. To summarise, although the air-side economiser was able to significantly reduce the energy consumption in comparison to the conventional cooling system, introducing the outside air to the IT environment resulted in a higher proportion of energy consumption of the humidifier and fans (the consumption of the fan is divided into categories according to the operational regime: direct outside air, mixing and humidifying & mixing) The energy consumption of the humidifier varies between 6% to 34.8% depending on the given climatic regions. Compared to other locations, the utilisation of the air-side economiser in the climate represented by Helsinki resulted in the most significant energy consumption by the humidifier; the humidifier consumed 233.6 MWh, which represents 34.8% of the annual energy consumption.

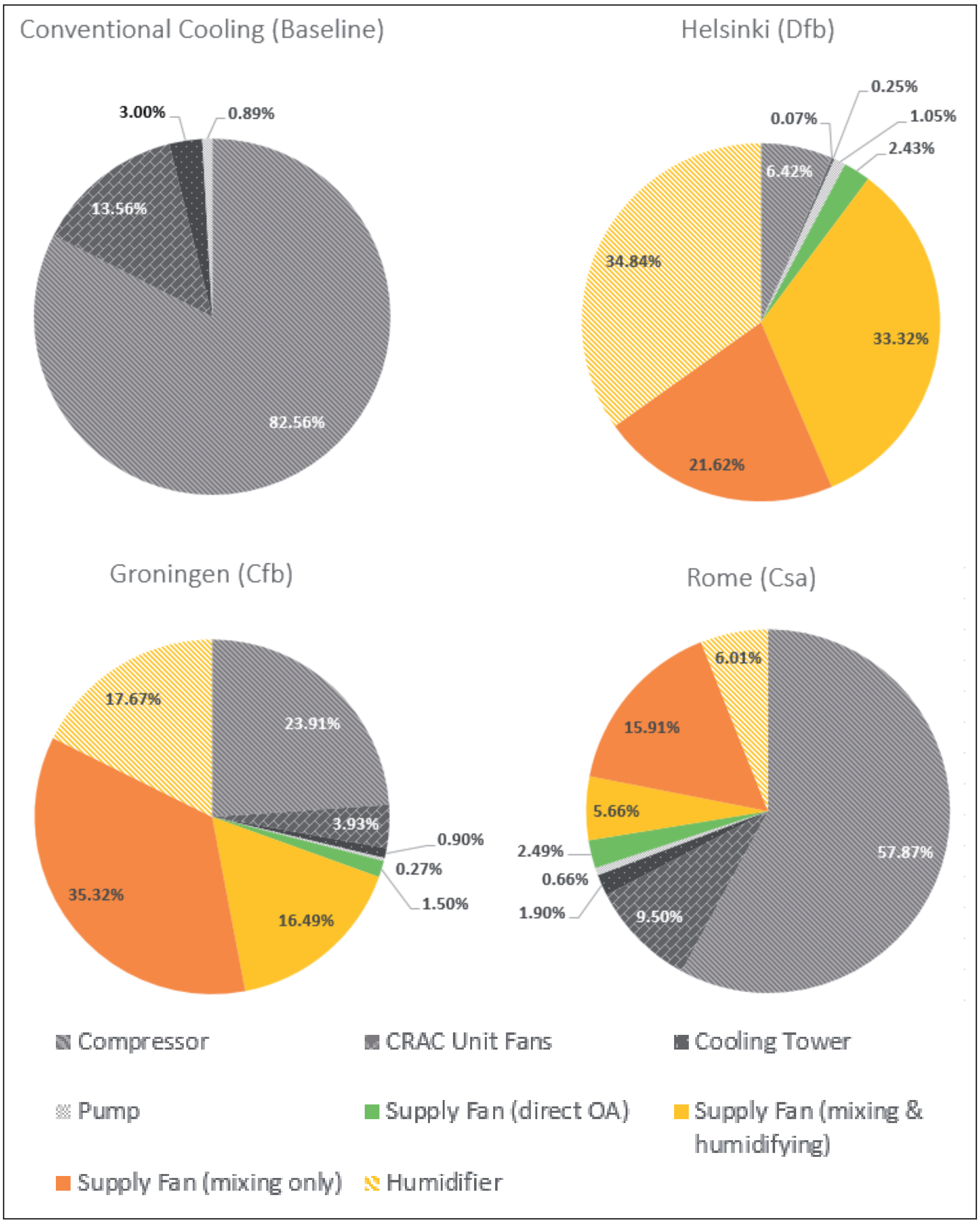

Fig. 7 The energy consumption breakdown by the individual equipment in percentage

CONCLUSION

The results presented provide an indication of the impact of the humidity treatment within the direct air-side economiser system. As expected, the air-side economiser offers a significant savings opportunity of energy use in comparison to the conventional cooling system. Since the economiser systems have become the new standard in data centre cooling, addressing the savings was not the main goal of this study. The key finding of this study was the energy breakdown of the cooling system using the direct air-side economiser, which includes the energy use of the humidifier. Even though, the air-side economiser was found to be a very promising way to improve the energy efficiency of the DC cooling, this research demonstrated that additional energy is needed to maintain the humidity level of the air supply to reach the recommended conditions suggested by ASHRAE TC 9.9. The results of this study indicated that the annual energy consumption of the humidifier in the system with direct air-side economiser varies between 6%, 18% and 34.8% for climates represented by Rome, Groningen and Helsinki respectively, which cannot be neglected.

In conclusion, this research has shown that the design of new-generation cooling systems with air-side economisers requires consideration with the humidity treatment and its energy efficiency. The impact of the humidity treatment can be relatively high, especially for the direct air-side economiser. The other economiser systems (e.g., an indirect air-side economiser) are generally less sensitive to the ambient environment, thus, the energy impact of the humidity treatment will be lower. Also, the energy demand of the humidity treatment can be also reduced using another humidifier device (e.g., a high-pressure fog system). Based on the study addressing the extreme situation, the highest possible impact of the humidity treatment was estimated to be up to 34.8% of the total DC energy demand.

Contact: Vojtech.Zavrel@fs.cvut.cz

References

[1] J. G. KOOMEY. Worldwide electricity used in data centers. *Environ. Res. Lett.* 2008, vol. 3, no. 3, p. 034008.
[2] P. DELFORGE and J. WHITNEY. Data Center Efficiency Assessment. *Nat. Resour. Def. Counc.* August, 2014.
[3] M. IYENGAR, R. SCHMIDT, J. CARICARI. Reducing energy usage in data centers through control of Room Air Conditioning units. *12th IEEE Intersoc. Conf. Therm. Thermomechanical Phenom. Electron. Syst.* 2010, pp. 1–11.
[4] M. DAYARATHNA, Y. WEN, R. FAN. Data Center Energy Consumption Modeling: A Survey. *IEEE Commun. Surv. Tutorials.* 2015, vol. 18, no. September, pp. 1–1.
[5] A. HABIBI KHALAJ, T. SCHERER, S. K. HALGAMUGE. Energy, environmental and economical saving potential of data centers with various economizers across Australia. *Appl. Energy.* 2016, vol. 183, pp. 1528–1549.
[6] W. TSCHUDI, P. SHREEDHARAN, T. XU, D. COUP, P. ROGGENSACK. Data Centers and Energy Use: Let's Look at the Data. In: *ACEEE Summer Studies on Energy Efficiency in Industry.* 2003, pp. 113–123.
[7] J. YOGENDRA, K. PRAMOD. *Energy Efficient Thermal Management of Data Centres*. London: Springer, 2012.
[8] ASHRAE Datacom Series. *High Density Data Centers Case Studies and Best Practices.* 7th ed. Atlanta: ASHRAE, 2008.
[9] J. CLARK. Humidity in the data center do we still need to sweat it? *The Data Center Journal.* 2012.
[10] APC Schneider Electric. Humidity Issued in IT Data Centers.
[11] The MathWorks. MATLAB 2014b.Natick, 2014.
[12] C. BELADY (Microsoft), A. RAWSON (AMD), J. PFLEUGER (Dell), T. CADER (Spraycool). Green Grid Data Center Power Efficiency Metrics : Pue and Dcie Editors. *Green Grid.* 2008, pp. 1–9.
[13] The American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE). *Thermal Guidelines for Data Processing Environments.* 3rd ed. Atlanta: W. Stephen Comstock, 2012.
[14] The Green Grid. Updated Air-Side Free Cooling Maps: The Impact of ASHRAE 2011 Allowable Ranges. 2012.
[15] V. K. ARGHODE, Y. JOSHI *Air Flow Management in Raised Floor Data Centers*. Springer, 2016.
[16] K. MACKAY. Energy Efficient Cooling Solutions for Data Centres. *Syst. Res.* 2007, pp. 1–128.
[17] B. A. HELLMER. Consumption analysis of telco and data center cooling and humidification options. *ASHRAE Trans.* 2010. vol. 116, no. 1, pp. 118–133.
[18] T. EVANS. The different types of air conditioning equipment for IT environments. *APC White Pap.* 2004, p. 24.
[19] S.-W. HAM, M.-H. KIM, B.-N. CHOI, J.-W. JEONG. Energy saving potential of various air-side economizers in a modular data center. *Appl. Energy.* 2015, vol. 138, pp. 258–275.
[20] T. J. BREEN, E. J. WALSH, J. PUNCH, A. J. SHAH, C. E. BASH. From chip to cooling tower data center modeling: Part I Influence of server inlet temperature and temperature rise across cabinet. In: *Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), 2010 12th IEEE Intersociety Conference on.* 2010, pp. 1–10.
[21] S.-W. HAM, J.-S. PARK, J.-W. JEONG. Optimum supply air temperature ranges of various air-side economizers in a modular data center. *Appl. Therm. Eng.* 2015, vol. 77, pp. 163–179.
[22] DANTHERM. Dantherm official. 2017.