Modelled and measured aerosol hygroscopicity for aerosol corrosion prevention and energy saving in green data center designing

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Industrial data centers (DC) are responsible for a large global electricity usage (~27% in Western Europe) mainly due to their cooling systems (35-50% of energy consumption) (Shehabi et al., 2008). Air conditioning (AC) costs could be reduced using a Direct Free Cooling (DFC) system which uses outside air to directly cool the information technology (IT). However this approach involves the risk to introduce outdoor aerosol which can become electrically conductive if the surrounding air reaches the aerosol Deliquescence Relative Humidity (DRH) thus causing bridging and corrosion that can damage the IT (ASHRAE, 2011; Shehabi et al., 2008).

Data Center Site

This study was conducted in Italy at Sannazzaro de' Burgondi (SdB, Po Valley), to specifically optimize the DFC (thermodynamic limits and indoor aerosol levels) of a DC, at the design, for the Italian Oil and Gas Company (ENI) (5200 m^2 of IT installed, 30 MW; $8*10^6$ m^3 h^{-1} of cooling air; www.eni.com/green-data-center/it_IT/pages/home.shtml) (Ferrero et al., 2013). The main aim was to design a DFC avoiding to reach the aerosol DRH: this increase the DC energy efficiency, whilst at the same time preventing aerosol corrosion.

Thus, Spring (24/03/2010-19/04/2010) and summer (10/06/2010-10/07/2010) campaigns were conducted at SdB to measure aerosol properties and meteorological parameters.

Experimental

PM_1 and $PM_{2.5}$ were sampled (4 hours; FAI-Hydra sampler; 2.3 m^3 h^{-1}, PTFE filters, Ø=47 mm) and chemically analyzed by means of ion chromatography (IC, Dionex ICS-90 and ICS-2000). The aerosol chemistry was used as an input parameter to calculate the aerosol DRH, using the Extended-Aerosol Inorganic Model (E-AIM; a state-of-the-art thermodynamic model for the H^+-NH_4^+-SO_4^{2-}-NO_3^--carboxylic acids-H_2O aerosol system Clegg et al., 1998; Pathak et al., 2004). The aerosol number size distribution was monitored through an Optical Particle Counter Tandem system ($TOPC_s$: 2 Grimm *1.107 "Environcheck"*; 31 size classes, from 0.25 µm up to 32 µm) allowing to asses the aerosol pollution level at the location of the GDC-ENI. $TOPC_s$ "wet" and "dry" data were compared allowing to the reconstruction of the hygroscopicity curve (Khlystov et al., 2005) to be compared with results estimated via E-AIM. Moreover an Aerosol Exposure Chamber (AEC; 1 m^3) had been specifically designed for studying the aerosol hygroscopicity by means of conductivity measurements as a function of the relative humidity: PM samples were housed over special PTFE supports, provided with a pair of electrodes each and conductivity measurements were carried out using the Hewlett-Packard 3421A acquisition module, while a T and RH were monitored using LSI-Lastem sensors. 1% RH step were obtaind by means of a evaporation unit filled with ultrapure, Milli-Q, water. Measurements were conducted at 25°C, the IT cooling set-point within the GCD-ENI.

Main Results

The E-AIM model was applied to each PM_x sample to estimate the DRH values. The average DRH for PM_1 was 61.2±1.1% (spring), and 68.4±1.4% (summer), while in the case of $PM_{2.5}$ it was 60.8±0.7% (spring) and 62.4±0.9% (summer). Lower DRH values during spring reflected the influence of aerosol chemistry: NO_3^- was predominant during spring (17-20% of PM_x mass), while SO_4^{2-} during summer (10-18% of PM_x mass); NH_4^+ remain fairly constant during both campaigns (4-7% in both cases). The obtained E-AIM output were validated using $TOPC_s$ and experimental AEC data. R^2 between $TOPC_s$ and E-AIM were 0.97 and 0.85 for PM_1, in spring and summer, and were 0.98 and 0.95, for $PM_{2.5}$, respectively.

Moreover, the AEC was used to measure, at 25°C, the aerosol hygroscopicity of a 15 $PM_{2.5}$ subset sample with the aim to validate if the E-AIM model. Considering the whole $PM_{2.5}$ subset, the averaged DRH estimated via E-AIM was 62.8±2.0% in keeping with the values measured using the AEC: 61.2±1.5%.

Therefore, E-AIM DRH_s values were used to optimize the DFC operating cycle: all the averaged DRH_s were found to be slightly higher than 60% allowing to choose 60% of RH as the upper limit for the DFC operating cycle to prevent a corrosive effects of the aerosol.

Thus, the energy consumption of the GDC-ENI was estimated considering, on annual basis, the total time when outdoor thermodynamic conditions allowed DFC operation. An annual energy saving of 81% was found, compared to traditional AC data centers: 7.4 MWh for 1 kW of installed IT and 221 GWh for the entire GDC-ENI. In terms of environment savings, t of CO_2 not emitted were estimated considering a CO_2 emission factor of 362 gCO_2 kWh^{-1} (European Environment Agency, EEA: http://www.eea.europa.eu/). Results evidenced an emission savings for each kW of IT: 2.7 t of CO_2 (80 kt the entire GDC-ENI), compared to traditional AC data centers.

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