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Solar energy and free cooling potential in European data centers

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Abstract

Energy efficiency has become one of the key issues for data center operators in recent years. Significant power and consequent cost savings are perceived to be attainable and are also considered to be mandatory due to environmental aspects and for sustainable development. Use of economizers and free cooling is currently one the most prominent ways to make data centers more efficient. Besides efficiency, solutions for green energy production are becoming more and more of a reality and while providing clean energy, intermittency is a considerable challenge, not least due to high reliability requirements in data centers. Solar energy, while currently being somewhat uneconomical solution, is expected to increase in the future with improved and cost-effective photovoltaic systems and due to its significant potential surpassing all the other renewable sources combined. Solar energy also has to a certain extent, when compared with e.g. wind energy, a more predictable pattern. It also correlates with temperature, making it an attractive source for systems in which power consumption is temperature related, such as with data center cooling. Unfortunately, locations with high solar energy production potential are somewhat less optimal for economizers and free cooling. This paper investigates basic relationships between solar energy and air temperature and subsequent data center cooling requirements. Of particular interest is the optimal data center location in terms of free cooling and solar energy potential.

Keywords: Data centers, solar energy, free cooling

1. Introduction

During the last couple of decades, data centers have become an integral part of modern society. As reliance on these computing systems grows by the day, so does also the power consumed by these systems. This rapid growth in energy consumption, which is perceived to being on an unsustainable path, has steered both industry and research community towards finding improvements and new solutions to the field of computing and data centers [1]. One of the key solutions has become the use of economizers in the cooling system. As traditional data centers have relied on chillers for cooling the heat load of the servers, a more modern approach is to utilize colder environments, where ambient outside temperature is low enough, to directly cool the data center, hence removing the need for chillers. This approach is perceived to significantly reduce data center power consumption, with estimates amounting to a reduction of one third or more of the total data center power consumption [2]. Consequently, data center operators have recently shown a great deal of interest towards colder environments with considerable number of materialized construction projects. Another aspect of the data center powering is the growing percentage of green energy sources,

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such as wind and solar energy [3]. While these project a significant challenges for data center operators in terms of reliability and economical aspects, they are set to increase in the coming years, not least due to governmental incentives towards sustainable development [4]. Wind energy is currently already a widely accepted and deployed source. It does suffer, however, from highly variable production. This intermittency remains a concern unless production is dispersed over a very large area. While wind energy production can be forecasted hours to days ahead, it lacks significant, predictable patterns. In energy production, the value of each source essentially depends on its ability to produce energy when load demands it. For renewable sources, this typically poses a great challenge as energy can be produced when it is not needed and may not be available when demand is high. To accommodate this misbalance, over capacity or energy storage is therefore often required, increasing the cost significantly. Solar energy is yet to see significant deployment, but recent developments and research prospects in the field of solar cells may well be the required catalyst for large scale use [5]. Unlike wind energy, solar energy tends to have more predictable patterns with both diurnal and annual cycles. Moreover, these patterns correlate with temperature, making solar energy an interesting energy source in systems whose consumption is related to temperature [6]. Countries in colder environments, like in Scandinavia, are an interesting location for data centers due to the cooling related savings. However, many of the renewable energy sources, like solar, hydro and wave energy, are limited, especially during winter time. Even wind energy is affected due to, for example, turbine blade icing effects. The availability of both, free cooling and renewable energy sources, is hence an important aspect on the road towards truly green data centers and computing. This paper evaluates the solar energy and data center free cooling potential in Europe. Section 2 reviews data center cooling related issues and temperature related power consumption estimates. In section 3 we review solar energy and temperature related phenomena and present data for four different European locations. Section 4 summarizes research results and is followed by conclusions.

2. Data center power consumption

Data center efficiency is, as well known, a highly complex topic. Sheer volume of different solutions, together with varying load and operating conditions make system analysis and power decomposition difficult [1]. Data center utilization level typically has a high impact on power consumption and can often be controlled to a certain extent, for example, to temporally level the load. In addition, data center equipment, like servers, exhibit a base or static power consumption, which in most cases account to a significant amount of the overall consumption. Cooling infrastructure is required to remove the heat generated in the system and as such, its consumption typically depends on the static and dynamic parts of the equipment consumption. The actual relationship between system utilization and cooling consumption is, however, dependent on the actual cooling equipment, i.e. chillers, fans or pumps and humidification equipment. Older equipment tend to have constant speed fans and chiller pumps, making their consumption somewhat constant and hence inefficient. Newer components are increasingly equipped with variable speed fans and pumps, allowing scaling with utilization. The chiller typically dominates the cooling consumption and this has lead to the use of economizers and various other free cooling solutions, which relieve the chiller operation either partially or wholly. These free cooling solutions utilize either cold outside air or a water reservoir, such as lake or sea for the source of cooling medium. Consequently, operation of these systems is contingent on environmental parameters; most importantly temperature. Air side economizers are so far the most common solutions due to cost and availability of equipment and water reservoirs. Air side economizers and free cooling solutions provide cool outside air either via heat exchangers or directly to the computer room and server inlets. The air temperature provided to the servers is an important factor and has to be within certain limits for reliable operation. ASHRAE has provided data center industry with general guidelines for recommended and acceptable temperature ranges. In their newest 2011 guidelines, given in table [7], ASHRAE has increased the acceptable ranges from 2008 guidelines to enable a wider use of economizers and free cooling.

Requirement for the outside air temperature understandably is the need for it to fall below the utilized ambient i.e. computer room or more specifically server inlet temperature. Heat exchangers exhibit a temperature drop, which according to ASHRAE can typically vary from 1.2 to 12 °C for various technologies.

Table 1. Recommended and allowable data center ambient temperature levels for various device classes according to the ASHRAE 2011 guidelines [7].

	Device Class			
Temperature range (°C):	A1	A2	A3	A4
Recommended	18 to 27			
Allowable	15 to 32	10 to 35	5 to 40	5 to 45

Direct air cooling does not suffer from this, but has other concerns, e.g. contamination and humidity control, of whose effects have been studied by [8] amongst other.

While there are studies done on the free cooling potential of various regions, such as the one done by The Green Grid [9], these tend to assume constant energy consumption regardless of the outside air temperature fluctuations. Moreover, these reports utilize ASHRAE's A3 and A4 class temperature ranges, under which very high operating hours, up to 8500 hours a year, are acquired for large regions around the globe. Within the recommended range, only northern parts of Europe have free cooling capacity above 8000 hours with southern parts falling between 5000 and 7000 hours annually [9]. Unfortunately, the server power consumption is known to correlate with the ambient temperature due to increased fan speeds and leakage currents in semiconductors and power conversion stages [7] [10] [11]. While there are thorough studies done on modeling the data center cooling infrastructure, including the behaviour of fan power, validations of these models and general measurements are still very limited. Moreover, despite there are several studies done on the effects of increased computer room temperature, results of which, are still somewhat debated, generalized and validated models of the total heat transfer from computer room to the outside environment are still lacking [12]. Acknowledging these issues, ASHRAE does provide certain estimates for the increase in power consumption as a function of temperature. These estimates, validated with actual measurements from commercial equipment, portray roughly 4 to 8% increase in server power when inlet temperature increases from 15 °C to 30 °C. And a 7 to 20% increase when inlet temperature is raised to 35 °C. ASHRAE also notes that even within the recommended range, operating at the extremes, fan power may make running the chiller a more economical solution.

3. Solar energy and temperature

Solar radiation arriving at upper atmosphere has a well defined behavior and can be calculated with high precision as a function of diurnal and annual cycles [13]. Activity of the Sun is essentially the only important and somewhat unpredictable component affecting the amount of incoming solar radiation. Radiation arriving at the earth's horizontal surface, referred to as insolation, however, is impacted by atmospheric conditions, such as cloud cover and humidity [14]. The surface temperature of the earth is known to correlate with insolation; as the latitude increases, the insolation drops quickly and this lower radiation per area causes a drop in average temperatures. Local conditions can have an affect on the temperature as for example ocean currents have heat transferring characteristics. Similarly cloud cover is related to local geographical conditions. One result of these is that inland areas are known to reach daily maximum temperatures at a later time when compared to areas close to shoreline. These temperature characteristics affect country wide energy balances, such as domestic heating requirements and as noted, can have an important role in industrial businesses requiring heating or cooling [15]. Harvesting solar energy could therefore provide a well balanced energy source with lesser effects from intermittency.

While the average insolation in northern countries is somewhat low, the typical photovoltaic system can be arranged at an optimal angle, thus receiving a higher amount of radiation per area [16]. When comparing insolation and radiation at an optimum angle, one can observe that the insolation and consequently the temperature drop quicker than the radiation received at an optimum angle for photovoltaic system. This essentially gives higher latitudes an edge for cooling intensive tasks as the ratio of photovoltaic energy versus temperature is higher. Current photovoltaic systems also exhibit variable efficiency which is temperature

Table 2. Estimates of solar irradiation and photovoltaic system output for various surface orientations. Values are provided by PVGIS [19].

	Helsinki, FI	Bremen, GE	Milan, IT	Sevilla, ES
Latitude	+60:10:00	+53:02:47	+45:28:18	+37:25:00
Yearly average global irradiation (kWh/m2):				
Horizontal surface	933	962	1244	1719
Vertical surface	829	775	957	1230
Surface with optimal inclination	1122	1101	1417	1950
Yearly average PV energy (kWh/1kWp):				
Horizontal surface	712	728	925	1250
Vertical surface	634	588	718	906
Surface with optimal inclination	849	828	1049	1411
Opt. average inclination	41	36	34	33

dependent. Photovoltaic conversion efficiency of silicon based cells increases with lower temperatures giving an extra advantage in colder countries. This has been researched for example by [17]. Results of these studies estimate the annual average efficiencies to vary from 75 % to 95 % for southern and northern Europe, respectively. However, future solar conversion technologies could become less sensitive to temperature. As next generation solar systems are actively researched, the prospects for solar energy are becoming more and more feasible. Development of better systems is perceived important for the wide adoption, mostly due to economical reasons [5].

Correlation between solar radiation or insolation and air temperature has been studied extensively, due to for example, its importance in agriculture. Various models have been constructed for analytical purposes. A general problem in model based evaluation of solar radiation and temperature related phenomena are the effects of local geographical environment and conditions. These tend to produce significant inaccuracies and some type of localized measurements are therefore required. Measuring and collecting large amounts of data has been a challenging task in the past and data is not often available for extensive periods of time, which nevertheless would be required to account for example, short term fluctuations. Available data is often averaged, making analysis of non-linear behaviour difficult. Average values also omit diurnal temperature variations.

To acquire an understanding of the latitudinal changes in temperature and consequent cooling requirements in data centers, we utilize maximum daily temperatures. Such data is available from various sources, e.g. the ECA&D research project [18]. This approach provides a somewhat conservative estimates, but avoids the problems with averages. More accurate temperature profiles could also be calculated from minimum and maximun values with methods such as the one discussed in [17]. Maximum temperature values are also of interest due to device class limits. Figure 1 presents temperature histograms and cumulative sums for four different locations in Europe. Latitudes have been selected to cover a wide area. Temperatures are from a period spanning from 1984 to 2004 and provided by ECA&D [18].

Solar energy potential in Europe has been mapped by various research projects, for example by PVGIS [19] and associated research [20]. Table 2 provides key solar energy values for the aforementioned four locations.

4. Results

From the data collected and presented in Table 2 and in the graphs of Figure 1, the latitudinal effects to temperature, insolation and output of photovoltaic system can be observed. The ratio of power output from optimally inclined PV system versus insolation increases with latitude, as was expected. Similarly, a drop in temperature is observable as latitude increases. When comparing temperature profiles given in Figure 1, northern locations, Helsinki and Bremen have essentially all of the days falling inside or below the

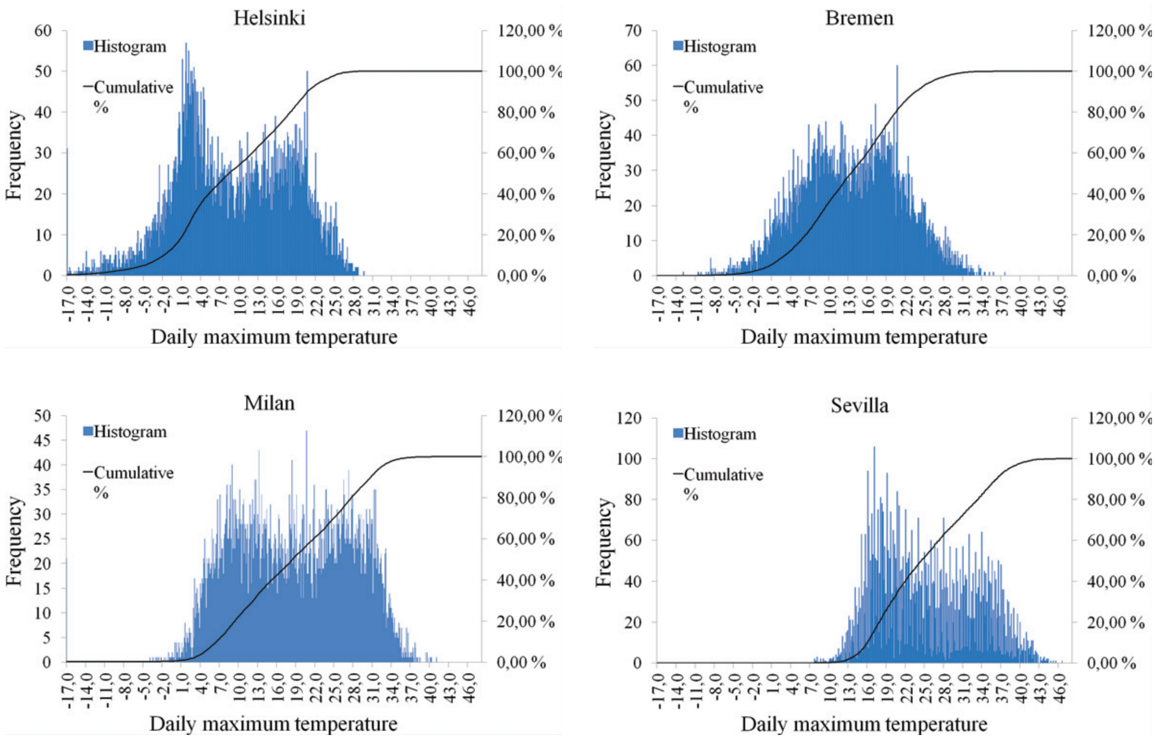

Fig. 1. Histograms and cumulative sums of daily maximum temperatures for four location in Europe spanning years 1984 to 2004 [18].

ASHRAE's recommended range. Especially in Helsinki, the number of days with maximum temperature exceeding 27 °C is close to zero. This essentially allows close to 100% free cooling with A1 class devices. When comparing northern locations in terms of photovoltaic production, Helsinki and Bremen are very close, with Helsinki having a slightly higher yield. The region around Baltic Sea is already known for its relatively high solar energy potential [20]. In southern locations, Milan and Sevilla, a significantly higher number of days, roughly 20% and 35% respectively, exceed the recommended temperature range. For Milan, class A3 could suffice for free cooling, whereas Sevilla would require class A4. Depending on economizer technology, a temperature drop of 1.5 to 12 °C should be added, making the prospects of free cooling even worse. Unless A2-A4 class devices are available, chiller is almost certainly required with Helsinki being perhaps the only exception.

As the temperature values in each of the four locations have relatively similar distributions, a rough efficiency comparison could be done based on temperature differences between the locations. For example, between Helsinki and Sevilla, a temperature difference of a little over 15 °C can be observed. In ASHRAE's terms, this would translate between 4 to 8 % increase in power draw. The ratio of solar energy yield between these two is significantly higher, favoring south. However, this is a somewhat oversimplified estimate due to non-linear behaviour of fan power, noted to start increasing exponentially above the upper end of the recommended temperature range. With Sevilla having significant amount of days exceeding 35°C, power increase could become severe. It should also be noted that the excessively low temperatures in north do not necessarily improve the free cooling potential any further.

5. Conclusions

Based on our research findings, while solar energy provides a source correlating to a certain extent with data center consumption, a combination with free cooling is a challenge with currently available technology. Despite the better solar energy to insolation ratio in high latitudes, there does not seem to be large enough difference to give an edge for these regions. This would seem to point to an optimal location residing somewhere between latitudinal extremes. However, the central Europe has relatively low solar energy potential making it in overall a less suitable region. The difficulties in assessing the free cooling potential due to somewhat limited availability of validated data and models should be noted. More accurate figures for the temperature effects would be required, preferably with analytical models. To make the comparisons more meaningful, capital expenses should also be taken in to account, as the need for chillers in warmer regions does offset the better photovoltaic economy. Savings from chillerless operation could be used to improve photovoltaic system, e.g. by 2-axis tracking. Future prospects of development in data center equipment and solar conversion technology, while generally promising, will largely determine how well these two technologies can eventually be combined.

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