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Reducing the Cooling Energy Consumption of Telecom Sites by Liquid Cooling †

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Abstract: The use of mobile data has increased and will continue to increase in the future because more data is moved to wireless networks such as 5G. Cooling energy need is also expected to increase in indoor telecom rooms, and can be as high as the equipment's own power consumption. The world's first liquid Base Transceiver Station (BTS) was taken into commercial use in 2018, in Helsinki, Finland. Conventional air-cooled BTS hardware was converted into liquid cooled BTS. Heat from the BTS was pumped out of the site room and thus ventilation or air conditioning was not needed for the heat load from the BTS. Heat stored in the liquid was released into the ventilation duct of the building, still providing annual cooling energy savings of 70%, when compared to air-cooling. In the future, 80% of the total dissipated energy, 13450 kWh/a in total, can potentially be used for heating purposes. In terms of CO_2 emissions, adapting liquid cooling showed an 80 % reduction potential when compared to air-cooling.

Keywords: liquid cooling; telecommunications; energy saving; Base Transceiver Station; carbon footprint; COP

1. Introduction

The power consumption of the Base Transceiver Station (BTS) equipment has been and will be increasing in the future due to growth in data transfer [1]. Heat dissipation from the BTS will be higher too, even if the efficiency of the equipment itself is continuously improving [2]. Due to rising heat dissipation of the equipment also the cooling of indoor sites needs to be increased. In current commercial BTS deployments only air-cooling is used, meaning that the site room is either ventilated or airconditioned to keep room temperature in desired temperature. Site rooms in telecommunications are not typically designed for equipment room use, but are free spaces in attics, basements, etc., where air flow distribution is not optimized. Impact of air flow distribution to cooling energy consumption have been studied in data centers and significant savings were achieved [3]. Therefore, air-cooling efficiency in BTS site is poor and site level energy consumption is growing even higher.

An alternative solution proposed is liquid cooling, where BTS is liquid cooled and heat from the BTS is transferred directly outside from the site room for dissipation or reuse. This would basically minimize the cooling need for the site room and provide energy savings for the communication service providers (CSP). Liquid cooling solution is closed loop circulation using direct contact cold plates, which are replacing the heat sinks and fans in air-cooled BTS.

The purpose of this paper is to describe results and findings of the world's first commercial liquid cooled BTS and to prove that cooling energy can be reduced and even reused. Liquid cooling for BTS is earlier demonstrated in a test system using artificial BTS load [4].

Measurements done for a test site in Helsinki Finland are described in the later part of the article. Results are showing that liquid cooling is enabling a significant energy savings potential for the CSPs and heat from the BTS can be used for building heating.

2. Materials and Methods

Key performance indicator (KPI) of the cooling is the Coefficient of Performance (COP) that is the ratio between the heat dissipation and the power used for cooling. In this study, COP for air-cooling and liquid cooling are calculated based on the measurements on live BTS site in Helsinki Finland between 29th of May to 26th of July 2018 for the air-cooling and 7th of January to 23rd of February 2019.

2.1. BTS Equipment

BTS equipment for air-cooled measurement was legacy equipment installed more than ten years ago. The system had 20 cooling fans, each consuming 10 W so the total power consumption of the fans was 200 W. The power consumption of the equipment fans was not possible to measure during the operation from the live BTS, but the value has been measured in laboratory earlier and matches the power consumption in the vendor data sheets [5].

For liquid cooling, modern BTS units with higher efficiency were used and they were modified to liquid cooling from the production version of the air-cooled units. In this modification, heat sink part of the BTS module was replaced by the custom-made cold plate that provides the same contact to printed circuit board (PCB) and components. Fans from the units were removed, because the vast majority of the heat is transferred to cold plate. Each unit is equipped with dripless liquid disconnects for easy installation and maintenance. In Figure 1, (a) air cooled BTS unit and (b) liquid cooled BTS unit are depicted.

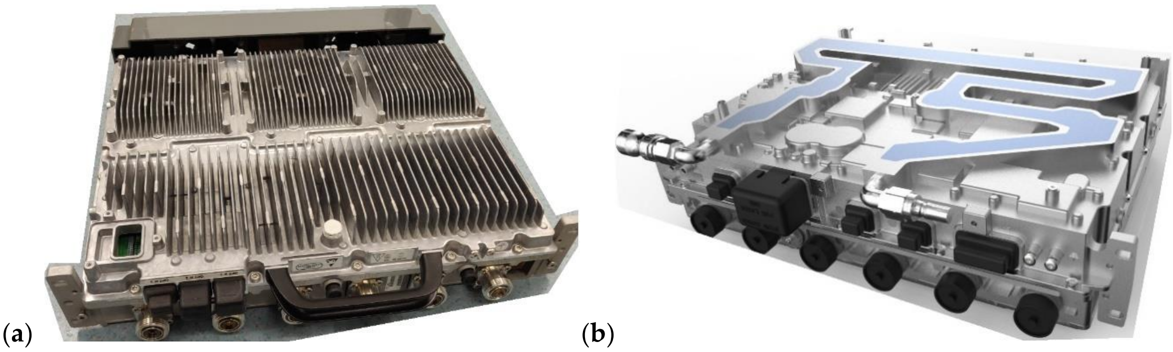
(**a**) (**b**)

Figure 1. (**a**) Air cooled BTS unit with a heat sink (**b**) same BTS unit with liquid cooling modification.

There were eight BTS units in total, both radios and digital processing units, in the liquid cooling setup. Additionally, there was an AC rectifier feeding the DC power to BTS units. The rectifier was liquid cooled, and it was modified the same way as the BTS modules by rectifier vendor using the existing air-cooled module. Power consumption of the digital processing unit is converted 100% to heat, but for radio unit part of the power is radiated from the antennas and it must be deducted from the heat dissipation. Heat dissipation of the BTS can be calculated as

$$Q = P - P_{RF}, \quad (1)$$

where

Q is heat dissipation
P is total power consumption of the BTS
P_{RF} is radiated radio frequency (RF) power to the antenna

RF power was not measured but estimated to be 480 W based on used configuration and it is same for both cooling systems.

2.2. Site Room Cooling

Original air cooling of the site was arranged by one site room fan that pushed fresh air in to the room and fresh air was exhausted from the vents. Fan control was based on the site room temperature sensor that turned the fan on or off based on the site room temperature.

The liquid cooling system on this site was built using typical heating, ventilation and airconditioning (HVAC) components. BTS units were first connected to manifold in parallel arrangement. Two pumps in parallel were used to circulate liquid in the loop, pumps were dimensioned to have full redundancy in case of one of them failing. Heat from the BTS was transferred to the heat exchanger (HEX) located outside of the site room in the building air ventilation channel. The HEX can be by-passed by the temperature controlled 3-way valve if the returning liquid temperature from the HEX is too low. Part of the heat is transferred to the thermostat-controlled room radiator which keeps the room temperature high enough during the winter time. Schematic of the site cooling is presented in Figure 2.

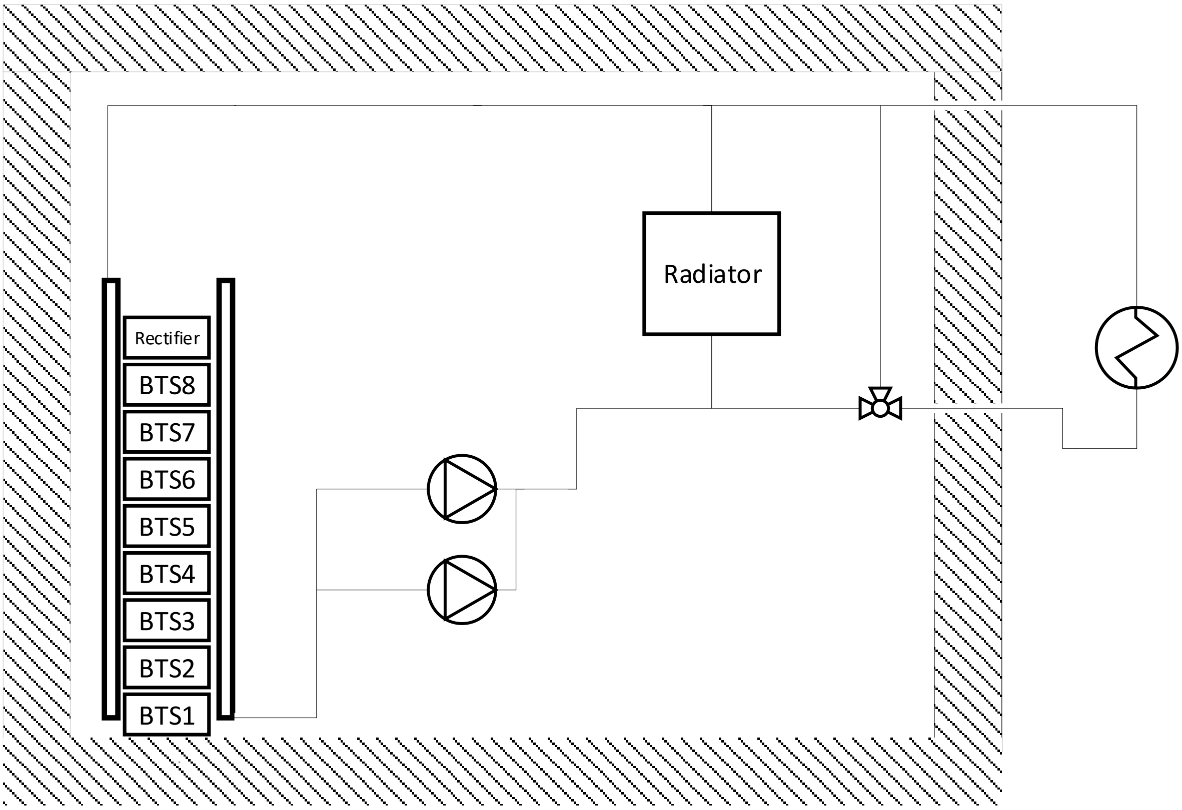

Figure 2. Site level liquid cooling schematic.

Liquid used in the setup is 40% ethylene glycol water mixture to avoid corrosion and providing adequate antifreeze properties.

2.3. Monitoring

In air-cooling setup, the total energy consumption of the site was measured. This power consumption includes the BTS and rectifier as well as the site room cooling fan. The energy consumption of the site room fan was not measured separately and thus it was assumed to run continuously. This is not true for the colder day, but for the sake of consistency the assumption was made. Hence its energy consumption can be calculated for the duration of the test session using the measured 244 W full speed power consumption. Site room external temperature was measured manually once a day.

For liquid cooling the daily energy consumption of the BTS and the site room cooling fan were monitored. Pumps were set to run at constant speed and they consumed 45 W power [6]. Also, site room external and internal temperatures were monitored for the test session.

2.4. KPI Calculation

Measured parameters were used to define different parameters to describe the effectiveness of the cooling. For both systems, COP is calculated as

$$\mathrm{COP} = Q/P_{\mathrm{Cooling}}, \tag{2}$$

For air-cooling cooling power is sum of the equipment fans and site cooling fans. For liquid cooling the cooling power consumption is sum of the pump and site room fan.

The dimensionless COP used for comparison eliminates the difference of the BTS types in the two cooling methods. The measurements were done in different times of the year due to the schedule of network installations, but external temperature difference is not too high and temperature range meets in around 10 °C.

Second important KPI is the site annual energy consumption of the site cooling, that is calculated using the measured average COP of the cooling system for a typical BTS site. Annual energy consumption is calculated as

$$E = Q/\mathrm{COP} \cdot 24\ \mathrm{h/d} \cdot 365\ \mathrm{d/a}, \tag{3}$$

3. Results

3.1. Aircooling Measurements

Average daily power consumption dissipation and external temperature for the air-cooling system are presented in Figure 3, for 59 days measurement session between 29th May and 26th July 2018.

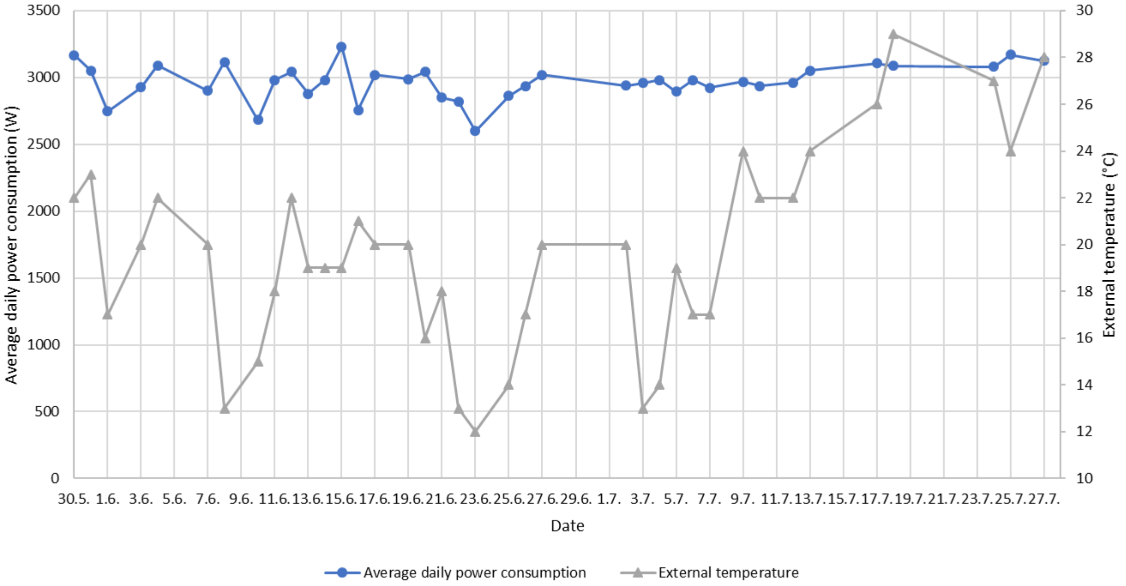

Figure 3. Daily power consumption and external temperature reading for the measurement session.

In Figure 3, it seems that power consumption is no correlation between the power consumption and the external temperature, but minimum points occur on the lowest external temperature days.

Individual COP points with a trendline for air cooling are presented in Figure 4 as a function of external temperature.

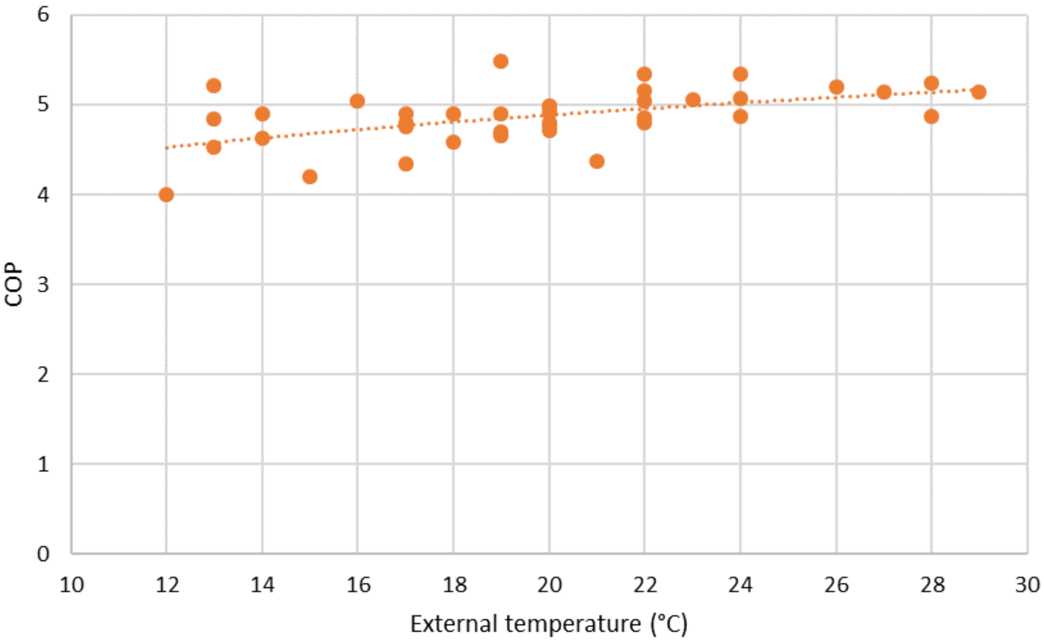

Figure 4. Calculated COP for different external temperature measurements with linear trendline.

Based on trend line presented in Figure 4, the external temperature has an impact on the COP, especially for external temperatures below 25 °C.

3.2. Liquid Cooling Measurements

Daily energy consumption of BTS and site room fans with external temperature are presented in Figure 5.

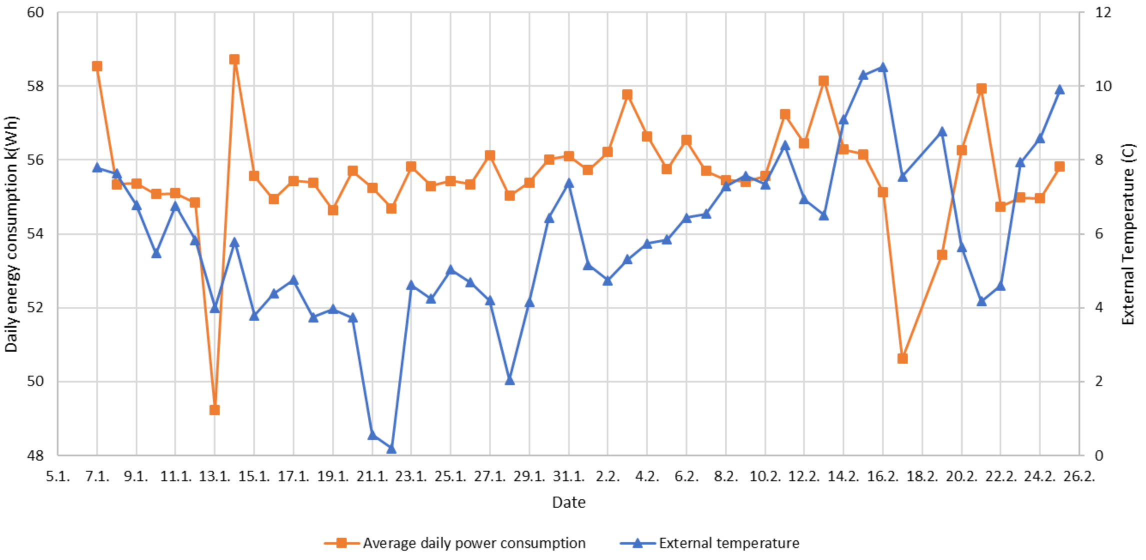

Figure 5. BTS and site room daily energy consumption and external temperature for liquid cooling measurements.

There is no clear trend in Figure 5 between the power consumption and external temperature as expected due to low power consumption for the cooling.

In Figure 6 it is presented the relationship between the calculated daily COP points and external temperature.

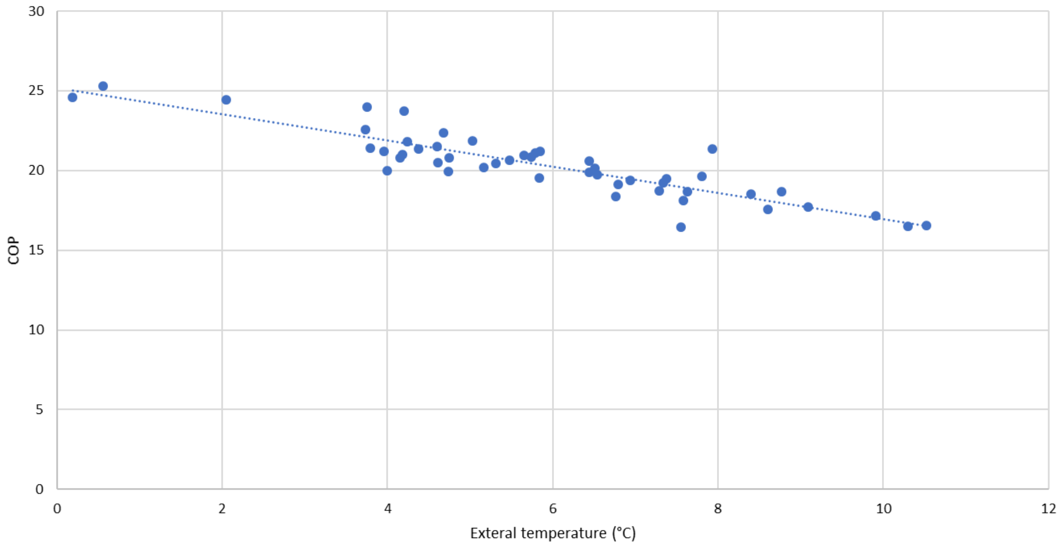

Figure 6. Calculated COP as a function of external temperature for the liquid cooling setup with a linear trendline.

In the trendline presented in Figure 6, the correlation between the COP and external temperature is visible and matches the expectations.

The annual energy consumption of cooling for a BTS consuming 2,3 kW is estimated in Table 1 for air and liquid cooling systems using the average COP value.

Table 1. COP and cooling energy consumption for air and liquid cooling systems, power consumption of the BTS 2300 W with 480 W RF power.

Cooling Method	Air Cooling	Liquid Cooling
COP	5	20
Annual cooling energy consumption	3190 kWh	800 kWh

Using the cooling energy consumptions from table1 the energy saving of liquid cooling is 75% compared to air cooling for the same BTS load.

4. Discussion

The energy efficiency of liquid cooling was proven to be better than that of air cooling. COP in same external temperature was three times higher for the liquid cooling than air cooling. This level of energy savings and the reduction of CO_2 emissions plays a significant role when scaled to entire network level with thousands of BTS sites per CSP. Calculated cooling energy saving of 75% represents 10% total energy savings at the site level. In addition to savings, 76% of the consumed energy on site was turned to heat that can be utilized, which can reduce the total net energy consumption on the site by 79%. The amount of reusable energy 15940 kWh is providing annual heating energy from 245 m^3 to 354 m^3 of living space in block houses, based on heat index in Helsinki area in Finland [7].

Site arrangements, together with monitoring limitations on the live BTS site, caused some challenges that did not allow for the full potential of the liquid cooling. The heat exchanger concept was not optimal since the airflow through the heat exchanger was not continuous but driven by the room internal temperature. Secondly, site room fan setting was not changed for liquid cooling and thus it operated more than needed. Finally, pumps were operated with constant speed, though they could have been controlled to lower power time to time depending on the BTS and site room temperature.

For air cooling measurement the assumption that site room fan runs continuously was wrong since calculated COP show decreasing trend for increasing external temperature, opposite to expected. However, it also looks that COP flattens out to the level of five on higher ambient which represents continuous fan operation. Thus, the initial assumption did not have a major impact on the final results.

5. Conclusions

Significant savings in energy consumption were achieved in this world's first commercial liquid cooled BTS resulting in 75% reduction of cooling energy need, that represents 10% saving in total energy consumption at the site level.

In future studies, the control of liquid cooling will be designed more precisely with a focus on further energy savings. Secondly, there is a plan to utilize the wasted energy for the heating of the building or utility water locally, that multiplies the savings due to energy saving in cooling and utilizing the BTS heat dissipation.

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Conflicts of Interest: The authors declare no conflict of interest.

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