Potential energy savings using a PID control methodology for forced-air cooling systems in mobile telecoms cell sites

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Abstract

It has been widely documented that the cooling of base transceiver stations is a costly, yet necessary function to ensure mobile telecommunications continue to operate. This requirement, however, is a non-added value expense; therefore, a reduction in this energy overhead would be ideal result to this study. Yet its impact is not only financial but also contributes to CO_2 emissions on a global scale due to the ever-increasing demand for mobile telecommunication connectivity.

Keywords: Forced air cooling, BTS, Base Station, PID Control, Efficiency, Cost Savings, Energy Savings, Global Energy Consumption, CO_2 Emissions, Environmental Control System.

Introduction

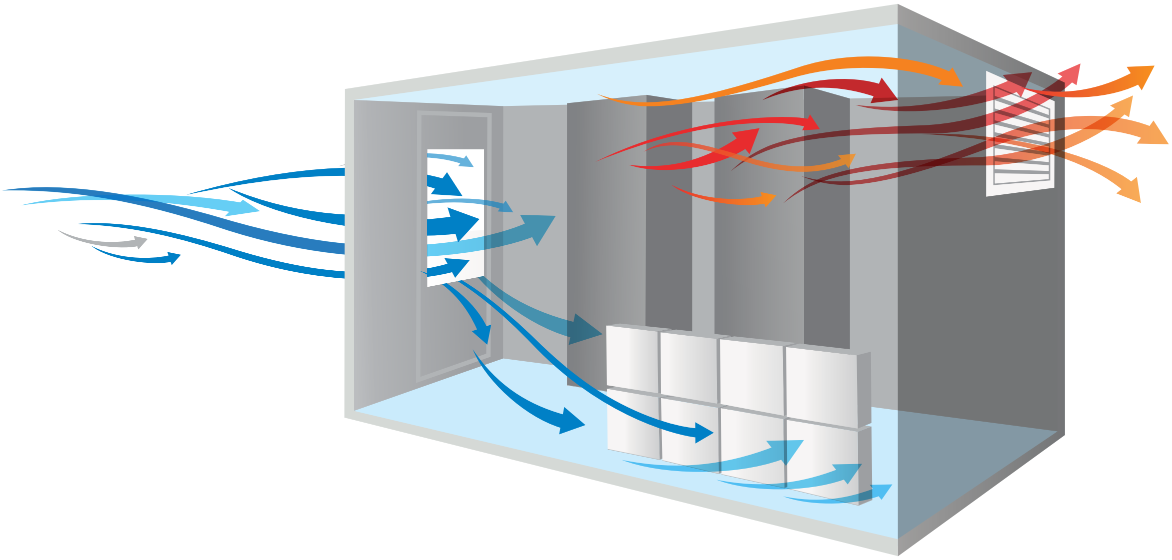
Mobile telecoms service providers operate a countrywide network of base transceiver stations (BTSs). The equipment contained within these stations, which connects the end users' devices to the network infrastructure, generates large amounts of heat, yet also cannot operate at temperatures in excess of 50°C; therefore, this equipment's environment must be maintained for the network to operate.

Throughout the mobile telecommunications industry, it has been reported that up to 45 percent of all power consumption in these stations is down to cooling of the equipment within.

As public demand for connectivity and area coverage increases, the cost incurred by mobile network operators to maintain these systems is only going to increase.

While forced-air cooling is not a new technology, with products such as CommScope's Monitor system currently providing cooling to BTSs (CommScope, 2020) around the world, the control system governing this system could potentially be improved upon.

The study proposes to investigate the potential savings in the operating expenses of the cooling system installed by moving from the existing "fan profile curve" to PID control, in both the system's development via simulation through software, and the OpEx via live trials "in the field" at six BTS sites throughout the UK.



Methodology

The trial system under PID control was observed over a 12-month period, and the data received from the trial sites was collated in the UK. During this trial the PID profile of the system was tuned to better suit the installation environment.

Initial trial system settings replicated the current fan speed profile of the Monitor system it replaced. By simulating the system and proving the model with real-world results, it may be possible to see savings in the energy used by the system.

The current Monitor system uses a fan speed profile determined by a "lookup table" stored in its system memory (Figure 1).

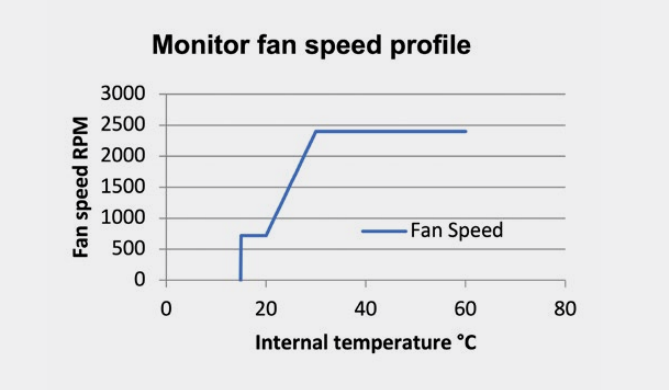


Figure 1. Current Monitor system fan speed profile

This fan profile was replicated through spreadsheet analysis, by retaining the system's setpoint at 15°C, and using P-Only control to create a linear profile of the fan's output over the remaining 15°C, as shown in Equation 1, where:

K_p is the proportional gain required.

FS_{Max} is the temperature in degrees Celsius at which the fan speed reaches its maximum output (100 percent fan duty).

FS_{Min} is the temperature in degrees Celsius at which the fan speed is zero (0 percent fan duty).

$$K_p = \frac{1}{FS_{Max}(°C) - FS_{Min}(°C)}$$

This results in a proportional gain value of 0.066. These values produce a pseudo fan speed profile (Figure 2).

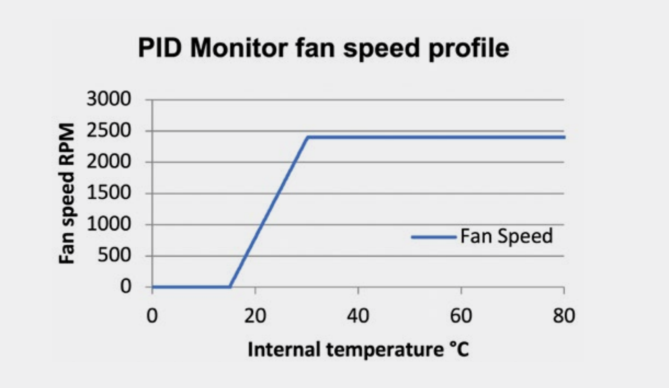


Figure 2. Replicated fan speed profile

The systems were installed and allowed to run as per the current system's settings. The data was periodically reviewed, and the system's parameters were modified to assess whether improvements to the cooling system could be made.

Energy demand for the cooling of base transceiver stations

The energy consumed by the cooling systems of base transceiver stations has been discussed by (Beghi, et al., 2017), who argue the energy consumed by BTS cooling equipment is approximately 30 percent that of the total energy consumed by the whole site. (Zhang, et al., 2017) suggests this value is more like 40 percent, whereas (Petraglia, et al., 2015) and (Spagnuolo, et al., 2015) state the value is between 40 and 45 percent.

And it is argued that approximately 0.82 percent of electrical energy consumed globally is due to the power requirements of base transceiver stations (Humar, et al., 2011). Taking a conservative value of 30 percent of BTS energy as consumed by cooling systems puts the figure at approximately 0.26 percent of the global energy requirement.

In its annual report (BP, 2019), the global electrical consumption for 2018 was stated as 26,614.8 terawatt-hours. Taking all these figures into account equates to 71.12 terawatt-hours of energy being consumed by the cooling of BTS equipment on a global scale. Hypothetically placing this electrical load within the UK, with the average cost of electricity currently 14.40p per kilowatt-hour (UK Power, 2019), would total over **£10 billion**.

The mobile network operator Vodafone Group has stated that the energy use of their base station sites globally in 2019 was 3,684 gigawatt-hours (Vodafone Group PLC, 2019). Again, taking the lower bound value of 30 percent, this would equate to 1,105 gigawatt-hours—costing the business an estimated **£159 million** per annum.

Any improvement on existing systems—even 1 percent—could make considerable savings in energy expenditure and CO_2 emissions.

Energy efficiency and CO_2 emissions

It has been stated by the (Committee on Climate Change, 2019) that the targets set for the UK's carbon budget set by The Climate Change Act 2008 (The Stationery Office, 2008) are not expected to be achieved during the fourth review period (2023 to 2027). More savings must be achieved to accomplish this set target of a reduction of carbon emissions to 51 percent below the levels recorded in 1990 (1950MtCO_2e).

A general rule of thumb for CO_2 emissions per kWh by (Hawkins, 2011) for grid-generated electricity states that, for each kWh consumed, the equivalent of 0.517 kg of CO_2 is emitted. Applying this figure to the 71.12 terawatt-hours consumed globally suggests that BTS cooling could account for up to 36 billion tonnes of CO_2 equivalent per annum.

UK climate

The UK climate is well documented by (CIBSE, 2019), with specific data on 14 large urban areas spanning the past 30 years.

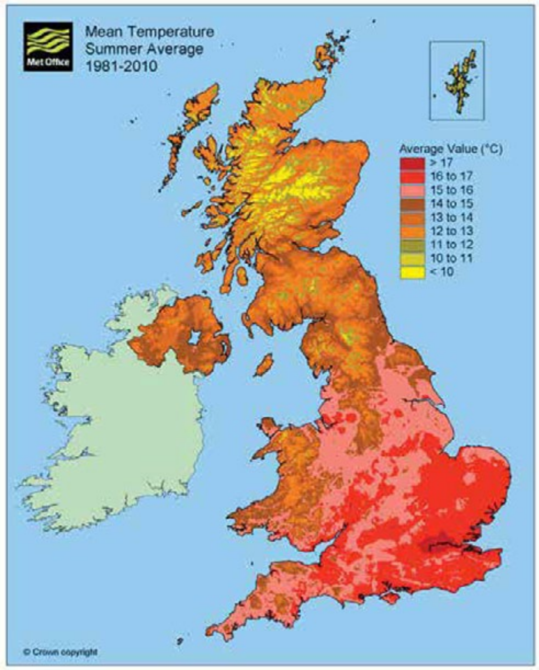


Figure 3. Mean temperature summer average 1981-2010 (CIBSE, 2019)

Figure 3 shows the average summer temperature across the UK, and Figure 4 shows the frequency of external temperatures experienced in London over the summer months (June, July and August).

The guide also suggests that London is the warmest region of the UK on average, due to the southeast region's proximity to continental Europe and the urban density of the city. Using the climatic data for this region, a forced-air cooling system profile could be designed and implemented effectively across the UK.

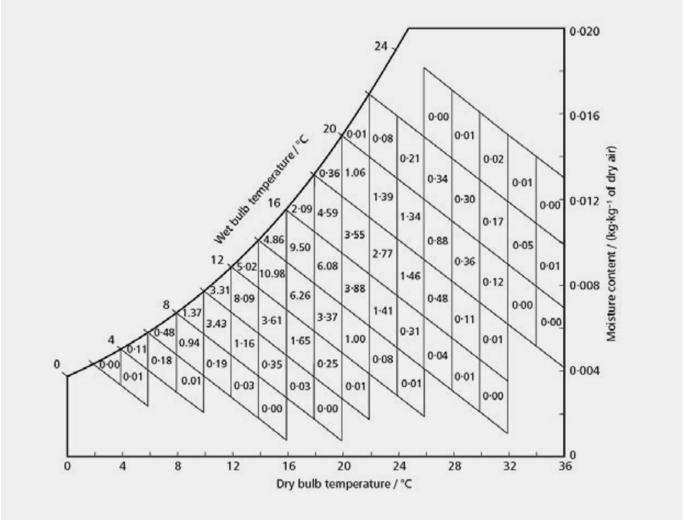


Figure 4. Percentage frequencies of wet and dry bulb summer temperatures in London 1982-2011 (CIBSE, 2019)

The (The Met Office, 2019) review of the year highlights key dates upon which to focus upon review of the data obtained, illustrated in Figure 5 below.

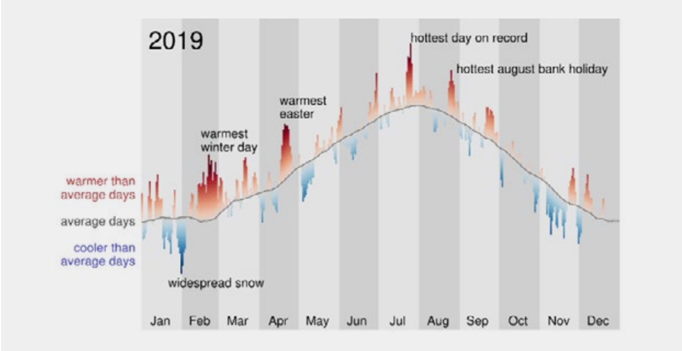


Figure 5. Average and extreme temperatures in the UK 2019 (The Met Office, 2019)

This guide, and other resources such as (The Met Office, 2019), may help pinpoint days of extreme temperatures to assess the system's operation efficiency.

Environmental envelope for base transceiver stations

Details for the preferred temperature range for BTS equipment are documented within (ETSI, 2014). The document refers to base transceiver stations as temperature-controlled locations, stating the internal air temperature should be maintained from 10-35°C for 90 percent of any time period (Figure 6).

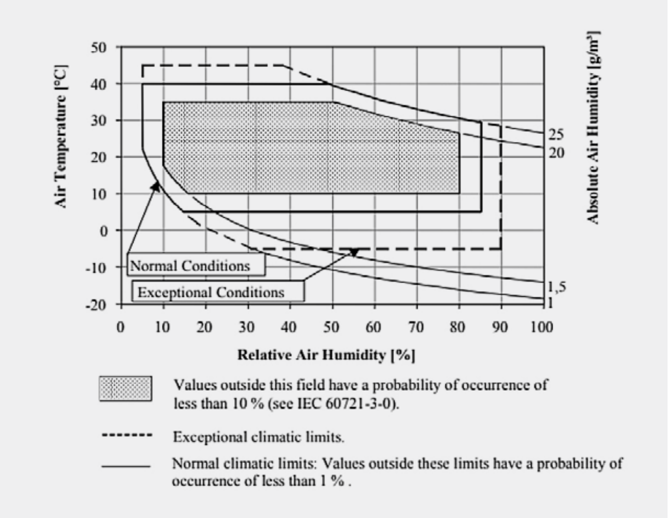


Figure 6. Psychrometric chart for base transceiver stations (ETSI, 2014)

This aligns with the environmental guidelines published by (ASHRAE, 2015) for air-cooled equipment in telecommunications facilities, which recommends an area of space for communications technology under some degree of environmental control to be maintained from 18-27°C, although 10-35°C is acceptable (Figure 7), defined as Class A2.

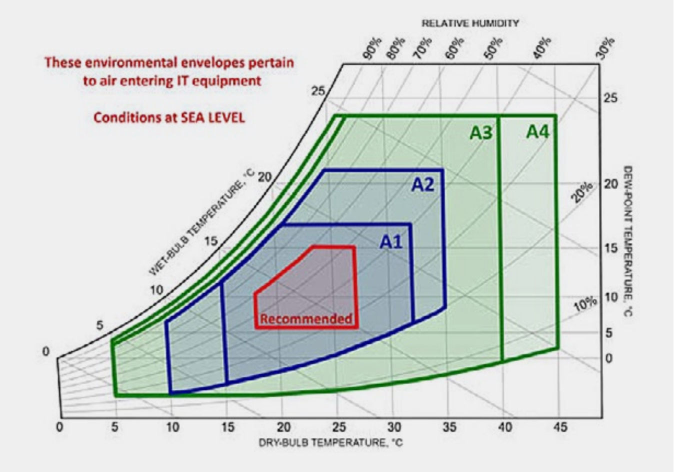


Figure 7. Environment classes for datacomms equipment (ASHRAE, 2015)

By aligning the cooling profile of the base transceiver stations and allowing the systems within to run at a higher temperature, the energy usage of the cooling system would decrease proportionally.

PID control

The requirements for efficient control to reduce energy consumption are well documented by (CIBSE, 2012), which states that any building control system should operate solely as and when required, and the use of closed-loop PI control techniques should be applied to maintain the process variable (internal temperature) within required tolerances to improve the energy efficiency of the system.

Research and analysis

Initially allowing the trial systems to run under P-Only control to establish a usage baseline for comparison (Figure 8) throughout December 2018 shows that the internal temperature of the BTS fluctuates in correlation with the external temperature, with the fan duty constantly above 30 percent to maintain this temperature.

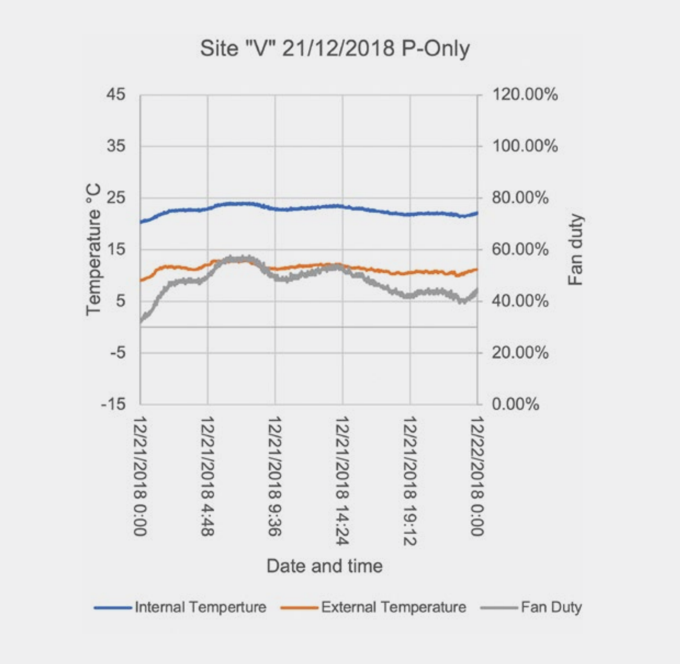


Figure 8. Internal temperature vs external temperature, with fan duty (site "V")

The other trial sites presented comparable results to those shown in Figure 8. Once baseline data had been established for all trial sites, the trial setpoint of 27°C, under PI control, was implemented.

By comparing the system response on days where the outdoor temperature was like those observed during the baseline period, the effectiveness of the trial system can be theorised.

Figure 9 shows the PI-controlled system site "V" maintaining the internal temperature at the desired setpoint, with the fan duty constantly below 20 percent.

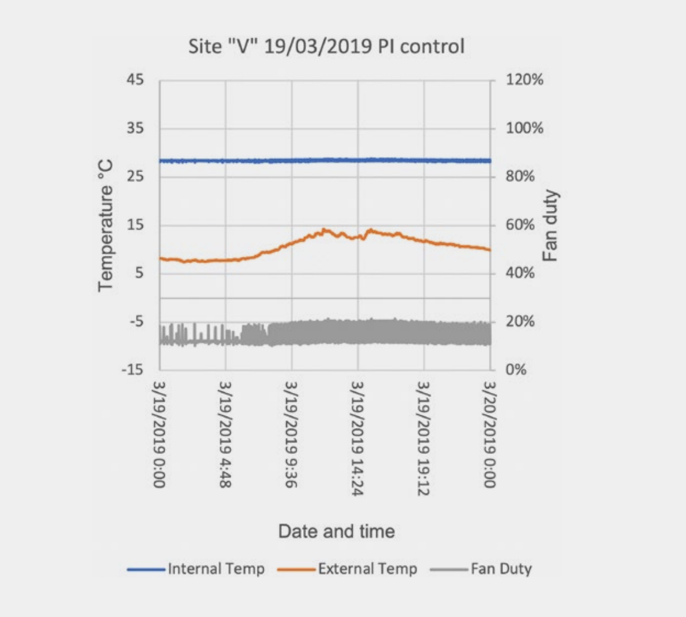


Figure 9. Internal temperature vs external temperature, with fan duty (site "V")

Establishing a setpoint for the system to achieve helped create a more stable environment in the mild conditions experienced throughout 2019.

Cold-weather extreme 2019

Observing the system over a period of extreme cold determined by (The Met Office, 2019), the internal temperature was observed to again correlate with the external temperature, as shown in Figure 10. At these temperatures the fan duty is 0, and the focus of the trial turned toward the temperature of the critical equipment—in this instance, the battery backup system.

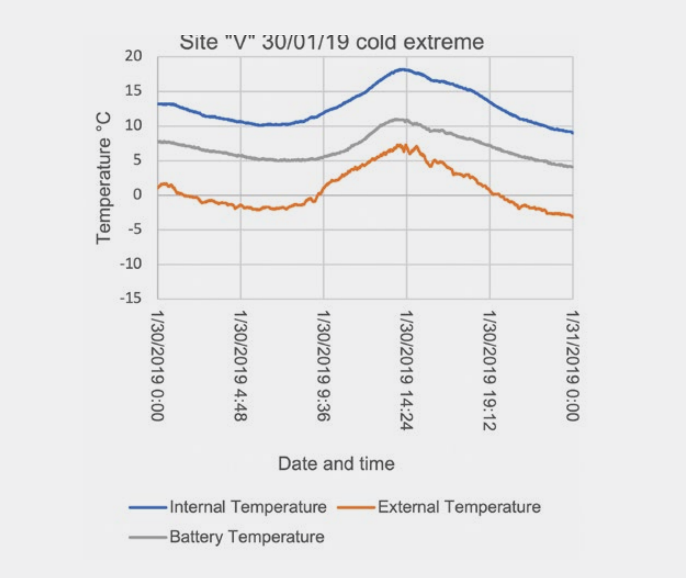


Figure 10. Internal and battery temperature against external temperature (site "V," original heat recovery setpoint)

At this extreme cold climate, the battery backup system temperature reached 5°C—far below the manufacturer's recommended operating specification, without the heat recovery system activating. Raising the heat recovery setpoint to 22°C directly increased the internal temperature (Figure 11). The controlled operation of the heat recovery system maintained the internal environment from 21-23°C until the external temperature increased (Figure 12).

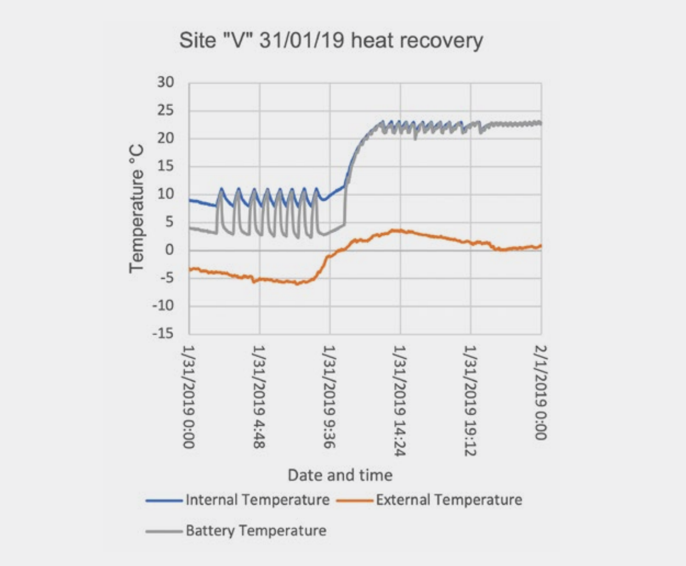


Figure 11. Internal and battery temperature against external temperature (site "V," revised heat recovery setpoint)

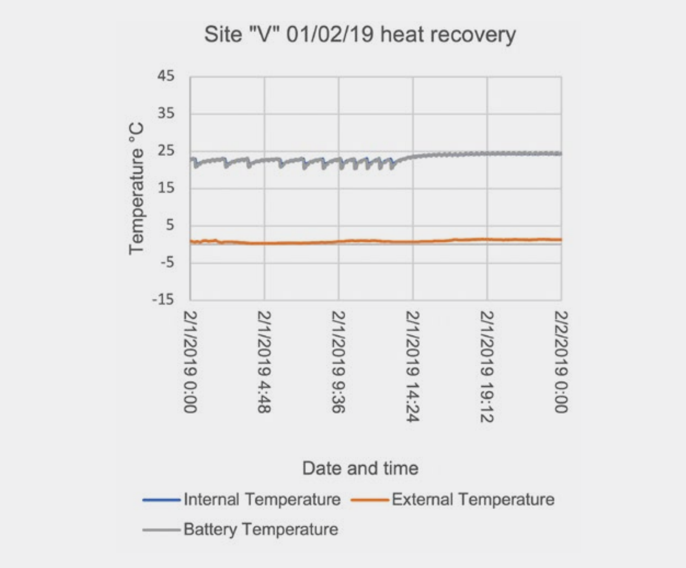


Figure 12. Internal and battery temperature against external temperature (site "V," revised heat recovery setpoint continued)

Hot-weather extreme 2019

On the hottest day of 2019, the system performed as shown in Figure 13. Observing the system performance of the other trial sites showed that the systems reached fan duty saturation throughout the day as the external temperature climbed above 30°C.

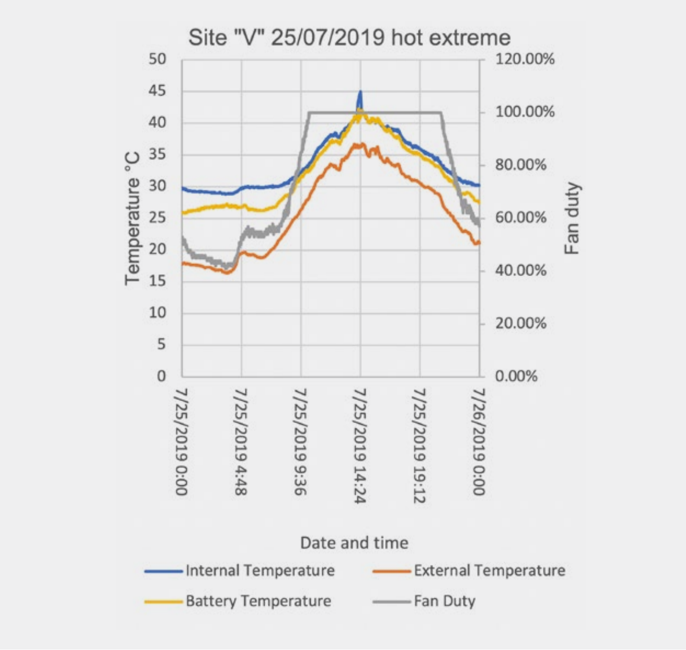


Figure 13. Internal and battery temperature against external temperature, with fan duty (site "V")

With site "V," the internal temperature—and the temperature of the critical equipment—exceeded the 35°C upper limit of (ETSI, 2014) and (ASHRAE, 2015) guidelines for 10 hours on that particular day. Comparing the likelihood of these external temperatures occurring shown in Figure 4, it is to be expected that these extremes are likely to occur on less than 1 in every 100 UK summer days.

Comparing this system performance to that of the current system's "curve," it can be determined that the lower values set in the system's lookup table would result in fan duty saturation at lower temperatures.

Conclusions and recommendations

Based upon the small sample of sites observed during the trial, the author has concluded that the current system of forced-air cooling is effective, yet its efficiency can be improved by implementing a PID control system with a narrow window of operating temperatures.

Operation parameters and setpoints

The existing system allows the internal temperature to fall as low as 8°C before heat retention functionality activates—allowing critical systems such as battery backup to fall well below manufacturer's guidelines for optimal operation, beginning the cooling process at such a low temperature that there is almost a constant demand on the system, and further compromising the critical equipment.

By raising the heat retention setpoint to 22°C on the trial systems, the internal temperature was maintained with no requirement for the movement of air through the BTS. It is recommended that the system profile be defined with this setpoint as default to maximise cooling through natural ventilation.

The existing system does not have a cooling system setpoint to achieve by the movement of air, instead operating with a lookup table of fan speeds against internal temperature. While the crux of the system is that the fans move more air through the BTS as the internal temperature rises, by defining a system setpoint as per the PID control system has shown increased stability in the internal temperature of the BTS. Furthermore, setting this value at 27°C reduces the duty on the cooling system and, while increasing the overall temperature of the environment, maintains the temperature of any critical equipment below 35°C for most of the summer months where higher external temperatures are experienced.

Critical equipment and sensor positioning

The positioning of the sensor controlling the system is vital to correct operation of the cooling system. The forced-air cooling system under observation utilises a NTC thermistor placed at high level in the centre of the room underneath, while other systems utilise a thermostat affixed to a wall.

While these components are placed to adequately control the climate of the room—in a position not in the path of the cooling air stream of the system—it may be more effective to place the sensor in the vicinity of any critical equipment, such as any transmission equipment or battery backup systems, so the environment may be better aligned to the parameters detailed in the manufacturer's guidelines.

Fan development

Further energy savings could be achieved by investing in the development and implementation of larger and more efficient fans and by increasing the number of fans in the system.

Increasing the number of fans in the system may provide further benefits, such as decreased duty on the systems, increased system lifespan, and overall reduced noise output from the system.

Acknowledgements

The findings presented have been made possible due to the continued support of the author's employer, CommScope, through the development of a new forced-air cooling control system, with the aim of increasing the efficiency of BTS cooling systems around the world.

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