White Paper

The impact of remote powering (PoE) on Balanced Twisted Pair Cables

"Powered Ethernet - heat effects on various categories of cables where will it stop?"

Powered Ethernet is a technology that continues to push accepted limits: the more power that can be delivered through copper Ethernet cables, the more industry wants to have available. The benefits are obvious: reduced cabling to equipment in terms of power and data comms provides financial, weight and real estate savings. While some disadvantages are also obvious, such as the failure of a cable bundle which exceeds its temperature limit, other disadvantages are less obvious and include changes in the channel performance during heating and potentially over several heating cycles. This paper builds on work presented at the International Wire and Connectivity Symposium (IWCS) to further analyse the effects on channel performance of powered Ethernet.

The discussion surrounding the impact of PoE (Power over Ethernet) on structured cabling and the heating effect that is caused by pushing a current down a cable that was not designed originally for that purpose has been gaining momentum in recent years as more and more powered devices are being deployed.

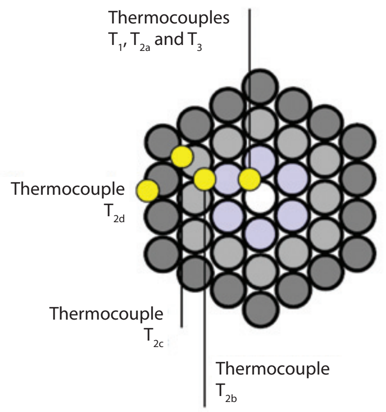
In 2010 the International Standards Organisation/International Electrotechnical Commission (ISO/IEC) published a technical report (TR 29125) that looked at ways to mitigate this heating effect, however many felt the initial testing model was not as robust as it could have been and didn't look into all the environments a twisted pair cable may be installed and therefore questioned whether it did give a reliable set of results.

Cenelec decided to produce their own Technical Report to look at ways of mitigating the heating effect of PoE however to do so it first needed to come up with a robust testing methodology. This was published in 2013 as the first element of TR EN50174-99-1. The proposed testing method has gone much further than previous examples, in the main by calling for the optimum bundle size that allows for at least 6 temperature probes or thermocouples to be employed, it also allows for the cable bundle to be, both in 'free air' and insulated, allowing a more realistic investigation of the impact of having cables installed within a range of sealed containment and unventilated spaces etc.

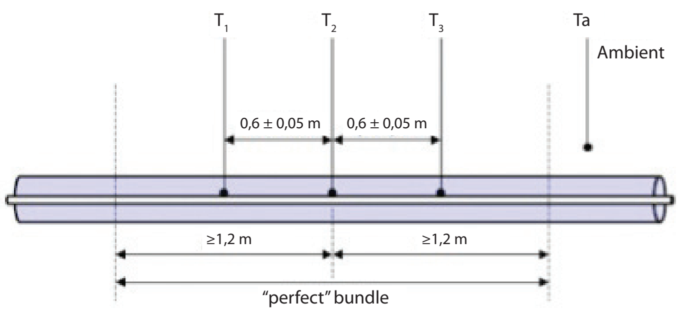
Today there are very few test rigs that have been constructed to carry out this level of testing and even less are said to be independent, one of which is at De Montfort University, Dept of Engineering, Leicester, UK. Excel Networking commissioned a series of tests under the guidance of Dr Alistair Duffy from the University. This paper will look at the results of that testing, the results will also be shared with Cenelec to help complete the work on developing TR EN50174-99-1

TR EN50174-99-1 Testing Methodology

The first stage of testing is to construct a rig that allows for a bundle of 37 cables to be suspended initially in 'free air' with thermocouples installed within each layer as shown in the following diagram.



As well as being distributed throughout the layers, thermocouples are also positioned along the length of the cable sample this is to measure the difference in temperature closer to the actual source of the power.



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In total 3 levels of testing were completed, PoE+ at 34.2 watts, UPoE at 60 watts and 100 watts which is a level being discussed by the IEEE for the development of the new 802.3bt, which has a stated minimum of 49watts and could be in excess of 100 watts when finally ratified, this also relates to some of the higher claims coming from proprietary systems such as HDBase-T which is a hybrid application intended for the AV market.

To get a true reflection of the impact these levels of power have on channel performance a range of cables we tested. The above applications are intended to operate over standards compliant copper twisted pair cables from Category5e U/UTP grade upwards, with a channel distance of up to 100m.

The following sample cables were initially tested Category 5e U/UTP, Category 6 U/UTP, Category 6 F/UTP, Category 6_A F/FTP, and Category 7_A S/FTP.

In addition we took the opportunity to assess the impact of using cables with construction which differ from the industry standard, for example such as a Category 6 cable that is 24 AWG rather than the more common 23 AWG. We also included a length of Copper Clad Aluminium (CCA) Category 6 cable, a lot has been written about the potential problems with these latter cables we wanted to get some real firm evidence.

Finally these tests were carried out both in 'Free Air' and contained within a glass fibre based insulating material commonly found within modern construction, the latter being a recognised method of simulating the effects of the cable bundle being contained within an insulating medium, whilst this may seem extreme it is important to note that some cables run either in high level tray or under a raised floor could run into many hundreds. We wanted to try to understand what may happen to a bundle of 37 cables in the centre of this mass, the test also provides evidence for the model to calculate the cables being in an unventilated containment for a prolonged period, for example 24 cables within dado or 3 compartment trunking is estimated at 80% of the value of the 37 cables. All the testing done to date has shown the cables do reach a 'steady state' after a given period when the heat increase levels out and this insulating material helps reach that point quicker. The 'steady state' can vary from 40 minutes up to over 30 hours depending upon the cable construction.

Testing Results

Before going into the details of the results it is important to understand, the background of the test methodology. The process is to create extremes of heat build up, to produce a worst case scenario from which a set of recommendations and mitigation strategies can be defined to ensure these scenarios are not reached never mind exceeded in 'real life' installations.

Therefore the following results will show some extremes of temperature increase over the ambience of the test room environment.

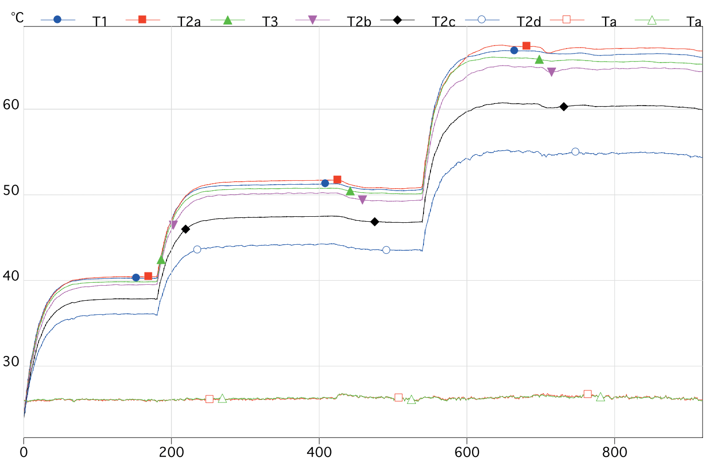
Category 5e U/UTP

This cable was of a standards compliant construction, 4 pairs contained within a LSOH sheath, conductor size being 0.51mm (24AWG) as seen in the table below the temperature increases at 802.3at and UPoE levels during the 'Free Air' tests are at an acceptable level, however when we get to 100watts results show it going beyond the operating temperature range of up to +60˚C stated within the cable construction standard EN50288-3-1. The Ambient Temperature (Ta) during this test was 23.36˚C + 41.02 = 64.38˚C

Test Date	20/3/2014
Test ID	001A
Wires used	8
Conventional test set-up	Yes
Cable type	LSOH Cat5e UTP
Cable diameter	5.2mm
Installation conditions	Free Air
Humidity at test end	40%
Average Conductor Resistance	0.098Ω/m
DC Loop Resistance	19.7 Ω/100m

Temperature Rise above Ambient					
Power	**T1**	**T2a**	**T3**	**T2b**	**T2c**
Watts	**°C**	**°C**	**°C**	**°C**	**°C**
34.2	14.21	14.39	13.79	13.4	11.8
60	25.09	25.52	24.57	24.02	21.33
100	40.38	41.02	39.62	38.63	34.29

During this test it took approx 180 minutes to reach 'Steady State' at 34.2Watts, 530 minutes at 60Watts and over 800 minutes for 100Watts before the temperature stabilised as shown in the following graph.



The most concerning results were recorded at the second stage of testing when the bundle of cables are encased in insulation and then the same levels of power were introduced.

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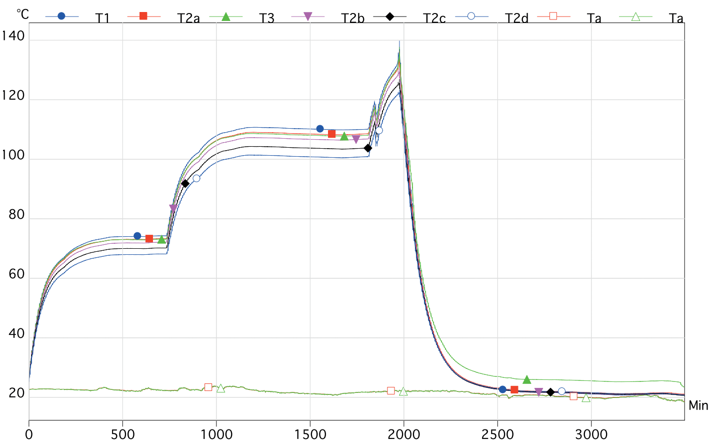
Test Date	21/3/2014
Test ID	001B
Wires used	8
Conventional test set-up	Yes
Cable type	LSOH Cat5e UTP
Cable diameter	5.2mm
Installation conditions	28mm X 25mm Foam Insulation
Humidity at test end	40%
Average Conductor Resistance	0.098Ω/m
DC Loop Resistance	19.7 Ω/100m

Temperature Rise above Ambient					
Power	**T1**	**T2a**	**T3**	**T2b**	**T2c**
Watts	**°C**	**°C**	**°C**	**°C**	**°C**
34.2	52.04	51.06	50.89	49.84	47.94
60	88.26	86.6	86.19	84.8	81.84
100	117.61	114.1	115.51	108.02	104.14

As we can see the actual temperature is outside the defined operating temperature range at all levels, Ta = 22.72˚C for this test. So with 100 watts we actually hit a peak of 140.33˚C. It also has a major impact on the time to reach 'Steady State' with 740 minutes at 34.2Watts. 1220 minutes at 60Watts. However it took a little over a further 100 minutes from the time that the 100 watts was introduced before the cable failed completely as is shown in the following table.



The catastrophic failure of the cable took us by surprise initially until we did some further research and some additional factors come into play. Firstly the resistance of the overall bundle changes during the heating cycle and that level of change is directly proportional to the temperature of the bundle. This has always been a known factor and is why we have always taken temperature into account when calculating the attenuation over a 100m channel.

The calculation for this is different for screened and unscreened cables using the formulas provided with EN50173-2. We were expecting to see as much as a 10% difference in resistance which is what we got.

However the extreme temperature increase had a major impact on the construction of the cable, the insulating material starts to lose its properties. The first thing that happens is that it starts to go soft and sticky which is again not overly surprising when you consider that the insulating polyethylene compound is extruded on to the conductors at a temperature of 160-180˚C therefore the copper conductors can migrate to the surface and eventually short out.

In speaking with compound manufacturers we were advised heating and rapid cooling can start to make the compound re-crytalise and lose some of its dielectric properties. Even if the conductors do not short, the cable will have lost the values that have been designed into the cable, for example Insertion Loss (IL), Return Loss (RL) and Next which are vital elements enabling system performance in line with standards.

Category 6 U/UTP

Test Date	23/3/2014
Test ID	002A
Wires used	8
Conventional test set-up	Yes
Cable type	LSOH Cat6 UTP
Cable diameter	6.2mm
Installation conditions	Free Air
Humidity at test end	40%
Average Conductor Resistance	0.075Ω/m
DC Loop Resistance	15 Ω/100m

Temperature Rise above Ambient					
Power	**T1**	**T2a**	**T3**	**T2b**	**T2c**
Watts	**°C**	**°C**	**°C**	**°C**	**°C**
34.2	14.02	15.89	14.45	15.3	14.17
60	22.9	26.2	23.77	25.35	23.39
100	35.16	40.67	36.82	39.38	36.36

The testing of the Category 6 U/UTP with 0.58mm (23AWG) conductors followed the same process.

In 'Free Air' the larger cable reached very similar temperatures as the Category 5e of the previous test, however one major change was the time it took to reach 'Steady State' it took 4 times longer at 34.2Watts=720 minutes nearly twice as long for 60Watts at 986 minutes and 1446 minutes at 100Watts.

The insulated values followed a similar trend although we included one additional level for validation purposes of 80Watts.

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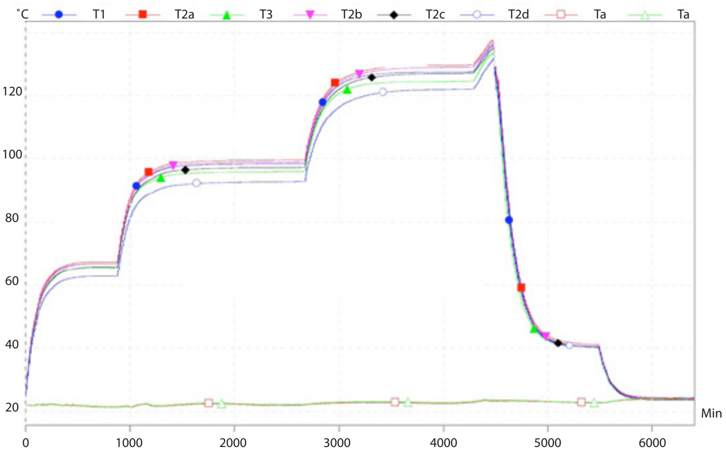
Test Date	27/3/2014
Test ID	002B
Wires used	8
Conventional test set-up	Yes
Cable type	LSOH Cat6 UTP
Cable diameter	6.2mm
Installation conditions	28mm X 25mm Foam Insulation
Humidity at test end	40%
Average Conductor Resistance	0.075Ω/m
DC Loop Resistance	15Ω/100m

Temperature Rise above Ambient					
Power	**T1**	**T2a**	**T3**	**T2b**	**T2c**
Watts	**°C**	**°C**	**°C**	**°C**	**°C**
34.2	45.42	46.01	44.15	45.39	44.29
60	76.34	77.55	73.91	76.92	75.26
80	104.66	106.8	101.58	106.14	104.25
100	112.62	114.34	110.11	113.35	111.37

Again the time taken to reach 'Steady State' was much longer, 80% longer for 34.2Watts, twice as long for 60Watts and a full 4,500minutes before it also failed at roughly the same overall temperature as the Category 5e which is over 2.5 times as long.



Therefore whilst the larger conductor size and polyethylene cross filler has slowed the heating process it still reaches the critical mean temperature which appears to be somewhere between 135-140˚C before cable failure, this slight variation could be accounted for by variations in the polyethylene compound used.

Category 6 U/UTP (Reduced Diameter)

Next we tested a reduced diameter Category 6 cable. These lower cost cable designs have appeared on the market in recent years to address market demands for cheaper products, and are marketed around cost and space saving benefits, whilst still claiming to offer 100 metre Category 6 channel performance. These reduced diameter, or HD cables have physical characteristics closer to that of Category 5e.

As already established a combination of the conductor size and the overall outer diameter can have a major impact on the findings of these tests.

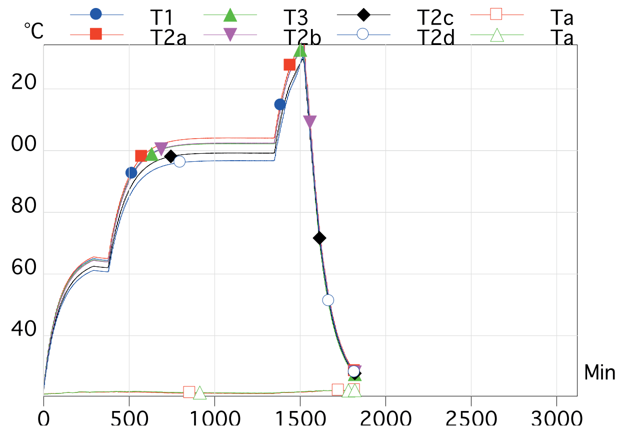
The first indication of the probable performance can be seen when you view the Conductor and DC Loop Resistance values, these are already higher than that of the 23AWG cable, part of which is due to the conductor size being closer to 24AWG at 0.52mm and an overall cable diameter of 5.4mm.

Test Date	5/5/2014
Test ID	006A
Wires used	8
Conventional test set-up	Yes
Cable type	Reduced Cat6 UTP
Cable diameter	5.4mm
Installation conditions	Free Air
Humidity at test end	40%
Average Conductor Resistance	0.082Ω/m
DC Loop Resistance	16.4Ω/100m

Temperature Rise above Ambient					
Power	**T1**	**T2a**	**T3**	**T2b**	**T2c**
Watts	**°C**	**°C**	**°C**	**°C**	**°C**
34.2	14.73	14.78	14.31	13.7	12.48
60	25.65	26.24	25.78	24.66	21.49
100	41.12	42.09	41.38	39.77	34.83

The next key observation is the time taken to reach a steady state is less than half the time when compared to 23AWG Category 6 cable.

When tested in insulation the Reduced Diameter cable actually failed overall quicker than the regular Category 5e cable.



Category 6 U/UTP (Copper Clad Aluminium)

This was a very intriguing set of test results, on the surface apart from not being solid copper, this cable did meet a number of the performance requirements for a Category 6 U/UTP cable, for example it had 23 AWG conductors, it also had a DC Loop resistance that was just standards compliant at 22.25 Ω/100m the limit being 25 Ω.

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However once testing began we found that the heating effects had a huge impact on the resistance of the cable, at first it increased dramatically beyond the 25 Ω mentioned previously. We therefore ran the test once more , this time the cable did perform as expected with a 'Free Air' temperature some 5-6˚C above that of the Category 5e and it failed at a temperature some 10˚C less when contained within Insulation. The following chart demonstrates the issue that we encountered and the temperature increase appeared closer to one end rather than the middle as seen with every other. We have also included the details of the resistance as a further indication of the risks attached to installation of CCA based cables.

Test Date	8/5/2014
Test ID	007A
Wires used	8
Conventional test set-up	Yes
Cable type	Cat6 CCA
Cable diameter	6mm
Installation conditions	Free Air
Humidity at test end	40%
Average Conductor Resistance	0.11Ω/m
DC Loop Resistance	22.25Ω/100m

Temperature Rise above Ambient						
	T1	T2a	T3	T2b	T2c	Resistance/100m
	°C	°C	°C	°C	°C	Ω
Initial Resistance						89
34.2W	16.23	16.20	15.86	15.23	12.86	
60W	28.60	28.48	27.99	27.09	23.07	
92.4W	42.1	42.2	41.8	40.24	34.11	
Final Resistance						99.9
Initial Resistance						DC Loop 22.5
100W	45.50	46.01	44.81	44.16	36.92	
Final Resistance						DC Loop 25.7

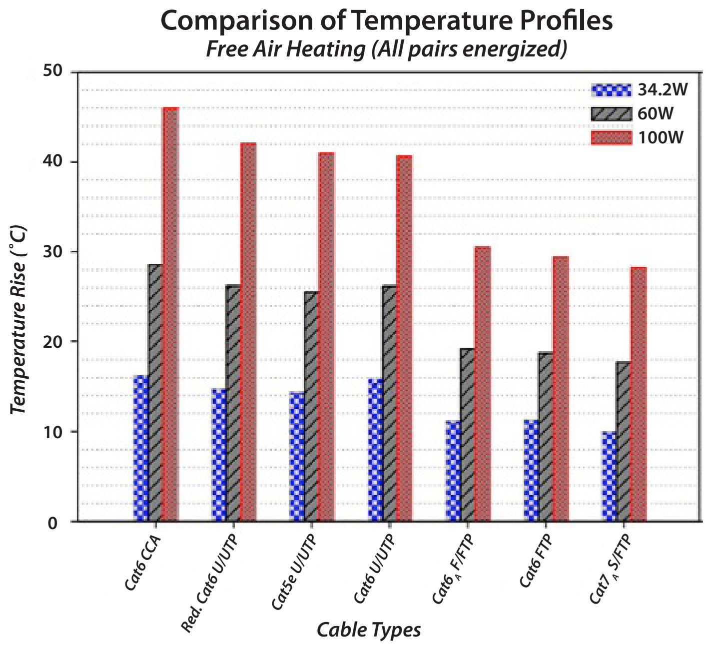
Category 6 F/UTP, Category 6_A F/FTP & Category 7_A S/FTP

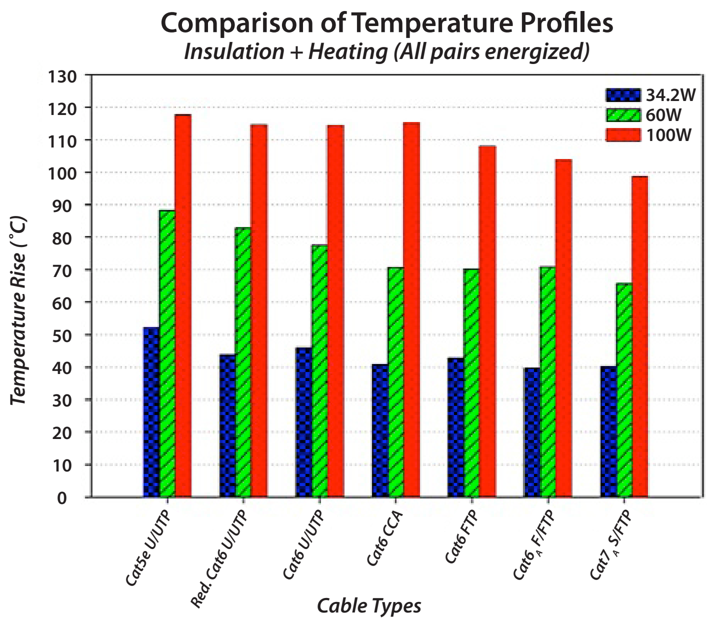
The remaining cables performed as expected with lower temperatures and longer time taken to reach steady state due to thicker conductors aligned with a larger outside diameter and screening construction. Full results can be made available upon request, however an indication can be found in the Summary Chart of all tests on this page.

The Category 6 F/UTP is 7.2mm in diameter, as we started to discover the larger the overall diameter of the cable the less it actually heats up, this combined with the Foil screen meant that it reached a steady state at 100Watts without failing. Purely out of interest we pushed the power level up to 107Watts before we damaged the cable, even then it took over 15 hours or 9,000 minutes to reach the overall failure level, remember the reduced diameter cable took just over 1,500 minutes.

Whilst the overall diameter of the Category 6_A F/FTP cable is slightly smaller at 6.9mm along with a combination of more screening material and a lower conductor resistance to begin with meant that whilst the cable reached a higher temperature in Free Air when in Insulation it performed better than the Category 6 F/UTP. Once a steady state was reached the cable continued to perform well for a long time, a decision was made not to try and continue to ramp up the power levels just to make it fail.

The same decision was taken with the Category 7_A S/FTP cable which has a 7.8mm OD and an even lower conductor resistance along with a large amount of screening. This cable recorded the lowest temperature level of 98.67˚C above ambient at 100Watts as well as reaching a steady state at around 3,000 minutes and not showing signs of going above that point.





The tables show the complete set of results for the cables tested whilst in insulation however they only indicate the maximum temperatures reached not the time it takes to get to that point, as previously mentioned the Category 5e, HD Category 6 and the Category 6 CCA, all failed very quickly after 100watts was introduced the 23AWG Category 6 U/UTP lasted much longer before it also failed. The common temperature appears to be approx 114˚C above ambient, before the dielectric starts to break down and eventually the conductors short with each other.

The other 3 cables never reached this crucial temperature to cause failure, the Category 7_A having both the largest conductors and outside diameter combined with a different screening construction.

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Conclusions

Whilst more analysis of these results will be needed by Cenelec and ISO/IEC before the full recommendations can be published we can certainly draw the clear conclusion that risk of degradation to system performance caused by the impact of remote powering devices over copper communications cables cannot be ignored and should be a key factor when specifying cable constructions, and performance categories.

During this testing we have highlighted that some cables have physically FAILED during the tests. The common temperature being approx 115˚C above the ambient temperature, however you must also consider that not all cables are run in spaces that operate at 21˚C some can be in air return spaces that have a far higher natural temperature.

Furthermore these results show a distinct and very clear argument for installing a Standards Compliant Category 6 cable rather than Category 5e or reduced diameter Category 6 cables which exhibit similar heating characteristics as Category 5e cable.

All the performance criteria for the 100m Channel as outlined in EN 50173-2 is based upon it operating at an ambient temperature of 20˚C and for every degree over this level this distance should be reduced. The following formula provided in the above standard gives the rate of reduction for unscreened cables, in short for temperature increases up to 20˚C above the ambient the Channel should be reduced by 4% and for temperatures over 20˚C above the ambient there is an additional 6% that has to be added.

Unscreened
$L_{t>20^\circ C}$=L/(1 + (T-20) *x* 0,004)
$L_{t>40^\circ C}$=L/(1 + (T-20) *x* 0,004 + (T-40) *x* 0.006)

This could potentially have a dramatic effect to the performance of installed cabling as recent research shows that the level of heating can be significant in some cases 30-40˚C above the ambient.

Screened Cabling performs much better, as the research has proved it does not heat up as much as an unscreened cable and when it does the de-rating formula is much simpler as it is based upon 2%.

Screened
$L_{t>20^\circ C}$=L/(1 + (T-20) *0,002)

Taking these calculations at some of the higher operating heat levels we have put forward, an unscreened solution may only ever possibly work at less than 75% of the intended distance.

It gives another very major reason, if it was even needed, why products such as Copper Clad Aluminium should be removed from our market place, as the failure is not just at a lower level than all the others it had a more erratic behaviour.

It is also evident that 4 pair powering has a significant impact on the heat build up witnessed, therefore UPoE is going to have more of an impact as it is rolled out and becomes more common place. When it comes to the proposed 802.3bt it may well be a step too far.

Other proprietary systems should be avoided at all costs the level of power involved is just too much for communications cable intended to transmit data. They claim that it can be run over a standard Category 5e cable but anyone reading these results will think otherwise.

Furthermore as we demonstrated anyone thinking of using a 26AWG solid core cable should seriously think again as it is not just about today it is about tomorrow which brings us on to the subject of 25 year Manufacturer Warranties.

All current warranties are written around current standards, irrespective of the manufacturer, they specifically relate to the operating temperature dictated in the cabling standards of -10˚C to +60˚C when we go outside these boundaries who is going to become responsible? The manufacturers of the system, the end users, the designers or the manufacturers of the equipment vendors who are trying to push more and more down the cable, when they are given an inch want to take a mile?

This Technical Note has been produced by F. Akinnouye, Dr A. Duffy (De Montfort University, Dept of Engineering, Leicester, UK) and Paul Cave, Technical Manager, Excel Networking.

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