Celsius Substation Intervention Tool

A guide to the tool developed as part of the Celsius project, including high level methodology and user guide.

Report for Electricity North West

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Contact:

Olivia Carpenter-Lomax
Ricardo Energy & Environment
Gemini Building, Harwell, Didcot, OX11 0QR, United Kingdom

t: +44 (0) 7525 902 555
e: Olivia.carpenter-lomax@ricardo.com

Ricardo is certificated to ISO9001, ISO14001 and OHSAS18001

Author:

Olivia Carpenter-Lomax, Michael Kelly

Approved By:

Simon Terry, Guy Wilkinson

Date:

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1 Introduction

1.1 Celsius Project Summary

The Celsius project was awarded funding under Ofgem's 2016 Network Innovation Competition (NIC). It is being led by Electricity North West (ENWL). Ricardo Energy & Environment are acting as key technical consultant project partners. The project started in January 2016 and was completed in March 2020.

The Celsius project has developed techniques and demonstrated solutions that can release capacity in existing secondary transformers, thereby potentially delaying the need to reinforce as the load grows. This includes:

- **A methodology for determining a more informed transformer rating**: This considers substation environment and monitoring data. It is noted that the nameplate rating provided on a transformer is conservative, and that under many substation environments and loading conditions, a higher rating may be able to be adopted. This rating is limited by the operating temperature of the transformer, and a more informed rating can be determined by comparing operating temperature with the transformer load and estimating the actual load at which the maximum allowable operating temperature will be reached.
- **Cooling technologies and solutions**: This can be retrofitted into the substation or on the transformer to lower the operating temperature, and therefore release additional capacity.

The first phase of the Celsius project trials and analysis involved 520 secondary transformers. These trials developed the methodology for determining an improved rating for the transformers based on measured data and site information. This analysis was based on detailed data and information gathered and analysed through statistical methods. This analysis was reported in the 'Secondary Network Asset Temperature Behaviour Report', which was re-issued in March 2020. This phase concluded that it is possible to identify a more informed rating from site information and data, and that the capacity release from this varies widely between sites.

The second phase of the project and analysis involved installing retrofit cooling technologies into 101 of these trial sites, to assess their benefits and impact on the more informed rating. This analysis was reported in the 'Celsius Retrofit Cooling Report', which was re-issued in March 2020. This phase of the report concluded that the following technologies may be of benefit when installed into a substation:

- **Active ventilation of substations**: Where air flow is increased though fans in order to cool the substation.
- **Improved passive ventilation of substations**: Substations generally have established passive ventilation arrangements, but it may be possible to improve these arrangements, particularly if the existing arrangements are not optimal.

Following this work, the learning from the two phases has been combined to form recommended updates to the business as usual (BAU) network operations. Part of this was delivered in the 'BAU Monitoring Solution Specification', delivered in September 2019, which covered the recommended process itself, and the requirements of the associated monitoring solution. A business case analysis for the implementation of Celsius techniques compared to traditional methods was developed and delivered in December 2019 and re-issued in March 2020.

As part of the development of business as usual recommendations, a tool was developed to allow users to access the learning of Celsius. The Celsius Substation Intervention Tool is an Excel tool which allows users to enter substation site data and gain back information about relevant site interventions and calculate a more informed rating. The functionality of this tool is described in this document.

It is intended that this tool is used by DNO personnel in various functions to explore the learning of Celsius using tangible examples and use it as a basis for planning the implementation of the learnings into BAU. The implementation itself will likely take the form of automated data collection and processing, and more detailed internal process documents will be developed, and so it is unlikely that the tool itself will form part of a BAU process.

1.2 This Document

This document includes the following sections:

- **Section 2: Celsius Substation Intervention Tool overview:** An overview of the tool functionality, including an outline of the two tools; the Celsius Intervention Tool and the Celsius Rating Tool.
- **Section 3: Celsius Intervention Tool:** A description of the functionality, use and limitations of the Celsius Intervention Tool.
- **Section 4**: **Celsius Rating Tool:** A description of the functionality, use and limitations of the Celsius Rating Tool.

2 Celsius Substation Intervention Tool overview

The Celsius Substation Intervention Tool has been built using the learning from the Celsius project. It can be used to understand the potential costs, capacity release and considerations for the relevant substation interventions investigated during the Celsius project, including monitoring and more informed 'Celsius rating', as well as retrofit cooling technologies.

The tool is in the form of an Excel document, and has been published and is available on the ENWL Celsius website.

The tool includes two parts, as described in Figure 1 below:

Celsius Intervention Tool

- Allows the user to input substation information
- Returns details about potentially relevant Celsius interventions, including the likely cost and capacity release.

The Celsius Rating Tool

- Allows the user to determine a more informed rating, or 'Celsius Rating' from input data
- Requires half hourly measurement data and site information.
- If only limited data is available, then the results are less reliable.

Figure 1: Overview of the tool

Each of these is detailed further in the sections below.

This version of the tool was developed at the end of the Celsius project. It is intended that the underlying learning and methodologies will continue to develop as the solutions are rolled out into business as usual DNO operations, and as a result, it may be appropriate to update this tool.

3 Celsius Intervention Tool

The Celsius Intervention Tool allows the user to input substation information and returns details about potentially relevant interventions. The tool can be used to suggest potential interventions from those trialled in the Celsius project and returns information about their cost and potential benefit. The interventions include:

- **Celsius monitoring and rating:** This intervention includes installing monitoring into the substation, including transformer surface temperature measured at the top oil level, ambient temperature measured at head height away from sources of heat and cooling, and three phase load monitoring. This data can then be used to calculate a more informed rating, which is highly likely to be higher than the nominal rating, which is considered a conservative rating. The difference between the Celsius rating and the nominal rating is the released capacity.
- **Celsius retrofit cooling technologies:** These include the technologies that were trialled during the Celsius cooling trials:
  - **Active Cooling** – Active cooling involves installing fans and associated equipment into the substation to force air flow in the room. Two active cooling technologies were included in the trials. The cost and benefit details included in the tool relate to the most successful of these.

- **Improved substation ventilation** – Alterations to the size and positioning of air vents in the substation building can be used to encourage natural air flow within the substation. This technique was trialled in 41 sites, including a range of building types, from brick substations, Glass Reinforced Plastic (GRP) enclosed substations, and substations that are part of a larger building.
- **Painting outdoor transformers** – Painting outdoor transformers with white paint could provide cooling benefit by protecting the transformer from solar radiation. This was trialled in 10 substations, but with mixed results, and was not included in the BAU recommendations.
- **Shading outdoor transformers** – Shades were installed at 5 substations. However, the available data was limited, and the trials did not conclusively show a benefit in the installation. This technology was not included in the BAU recommendations.

The tool shows the benefits as a range of capacity released. The Celsius rating benefits are derived from the trial data by comparing the calculated Celsius ratings to nominal rating. For the cooling technologies, a Celsius rating before and after installation of the cooling technology is compared. The range indicates the spread of results.

To guide the user, the tool also provides an average capacity release across the trial sites. The data used for this analysis was filtered to ensure it was of a high quality, and that a valid Celsius rating can be obtained. This means that not all of the trial sites could be included in the analysis. The number of trial sites indicated in the tool for each technology are those sites which could be included in the tool.

The costs provided in the tool are taken from the trial experience. The range of costs provided reflect the range of costs for the different trial sites, which is based on site-specific characteristics. A BAU implementation of the cooling technology may be a lower cost to that experienced in the trial, due to economies of scale. However, this effect is unpredictable given uncertain volumes. The monitoring solution and Celsius rating costs include only the cost of the monitoring equipment and installation effort. This assumed that the data and communications solution has been identified and implemented.

The diagram below in Figure 2 below describes the tool functionality.

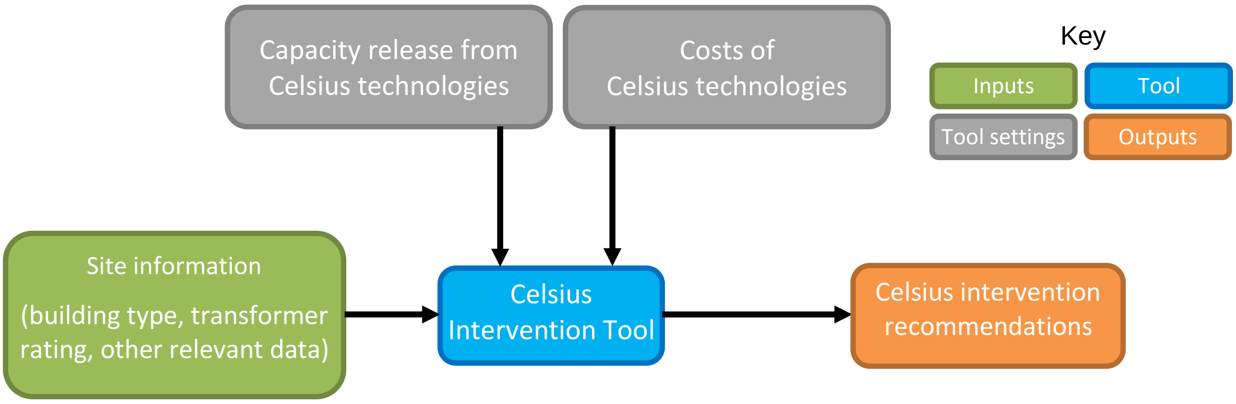


Figure 2: Functionality of the Celsius Intervention Tool

Figure 3 below shows the tool, with the input and output fields indicated.

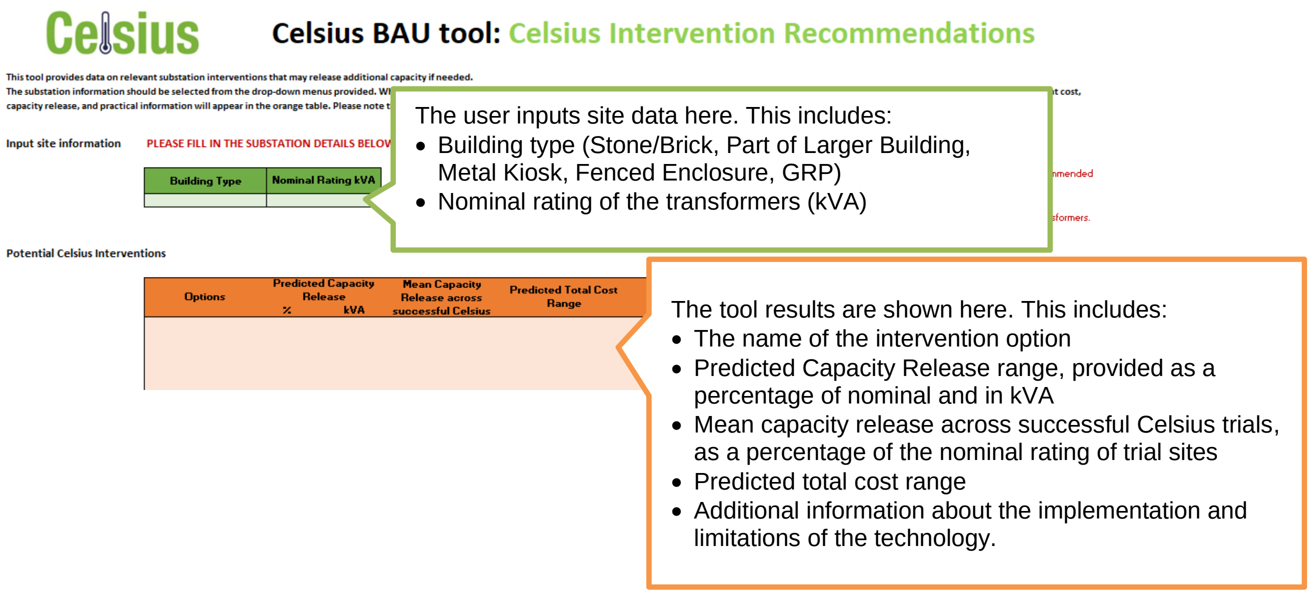


Figure 3: Image of the Celsius Intervention Recommendations tool with input and output fields indicated.

4 Celsius Rating Tool

The Celsius Rating tool allows the user to determine a more informed rating, or 'Celsius Rating' from input data, including half hourly measurement data and site information.

Two versions of the Celsius Rating Tool have been developed;

- one which uses only site data and information, suitable for indoor sites only; and,
- one which also includes weather data, which is suitable for outdoor sites.

Figure 4 below describes the tool functionality.

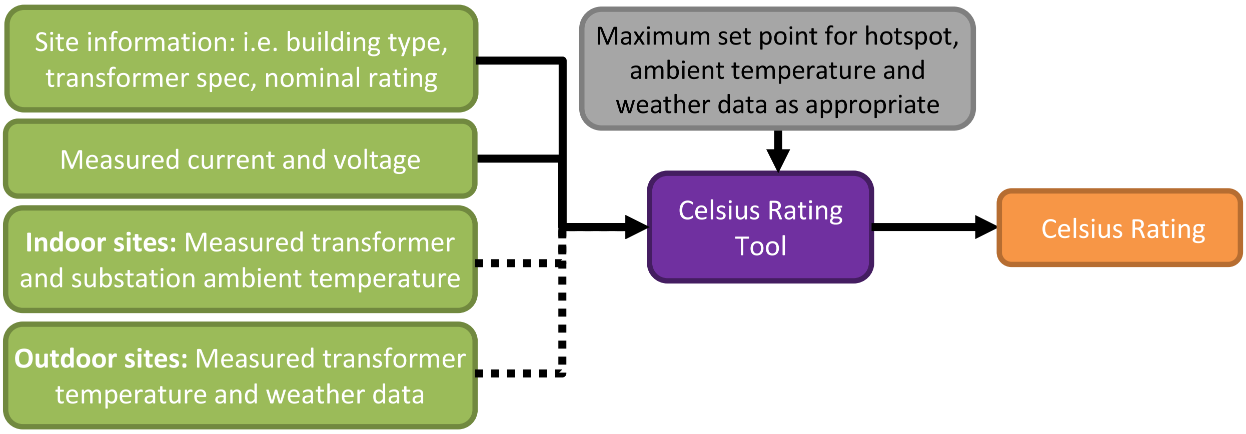


Figure 4: Functionality of the Celsius Rating Tool

The model requires substation information including the transformer specification, transformer rating and the building type. It also required the following measurements:

- **Transformer surface temperature:** Measured at the top oil level
- **Ambient temperature:** Measured away from any sources of heat or ventilation and cooling, and measured at approximately 2m off the ground (only relevant for indoor sites)
- **Load data:** In the form of three phase current and voltage

- **Weather data:** Including weather temperature and wind speed (only relevant for outdoor sites)

This data must be in half hourly measurements, and the site must experience some heavy loading, beyond 60% utilisation.

It was identified that to maximise its usefulness, the tool should be able to produce a Celsius rating using a minimum of 2 weeks' worth of data. In order explore the validity of these ratings, Celsius ratings were calculated for existing sites within the Celsius trial based on 2 and 4 weeks' worth of data throughout the year and compared with the Celsius rating calculated from up to 3 years' worth of data. The results are as shown in Figure 5.

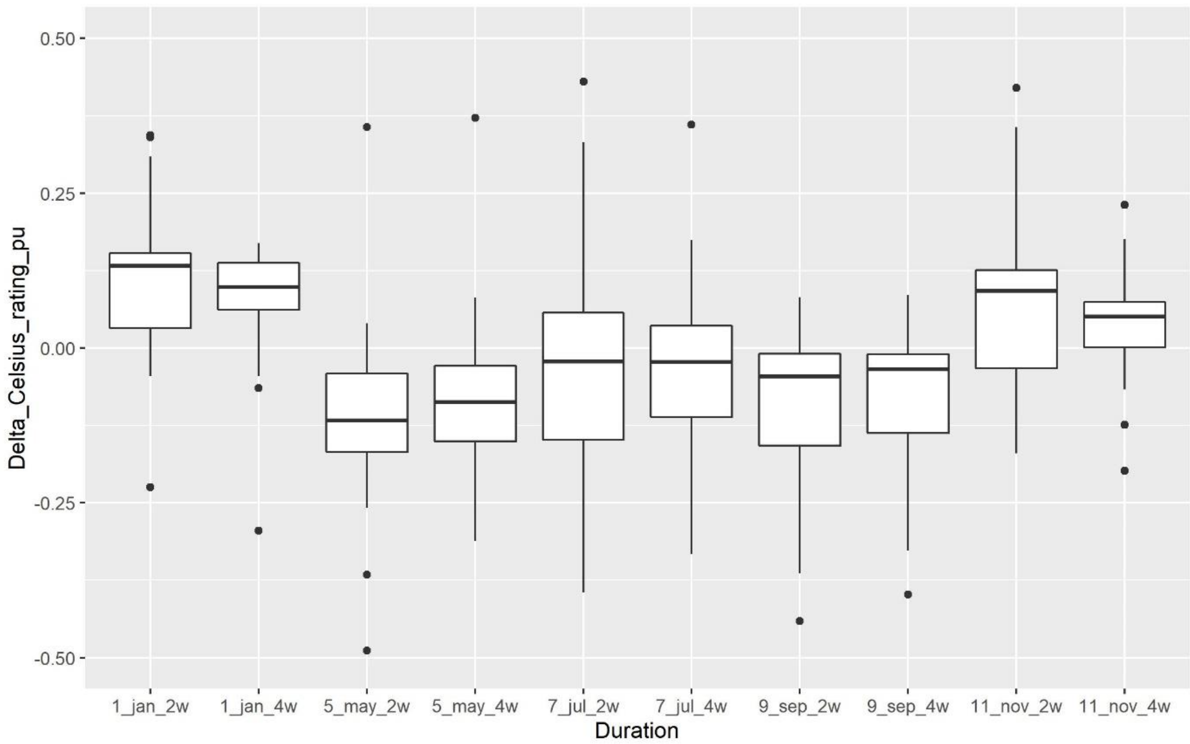


Figure 5: Comparison of Celsius rating calculated from 2 and 4 weeks' worth of data and the baseline data which was for more than 3 years

The results show that generally the Celsius rating calculated with 2 or 4 weeks' worth of data is within 15% of the Celsius rating when calculated with 3 years' worth of data. However, there are cases where the discrepancy is more than 30%. The results suggest that for 2 and 4 weeks of data the Celsius rating is being overestimated in summer in comparison to the result that would be generated if more than 3 years of data was used. In contrast, in winter the Celsius rating for 2 and 4 weeks is underestimated. Overall the distribution is consistent across the different months in the year which lead to the tool being designed to have at least 2 weeks of data ready to be entered.

This illustrates that though the Celsius rating from a short-term indication of load does yield results, it is essential that the monitoring is continued in order to gain a full Celsius rating and to continue to benefit from the solution.

Two maximum set points are embedded in the tool to enable rating calculation:

- **Maximum hotspot temperature:** This is the maximum temperature that the hotspot can be allowed to reach during operation. This is set to 98°C which was taken from ENW's code of practice document.
- **Indoor sites only – Maximum ambient temperature:** This is the maximum ambient temperature that the substation is likely to reach within the year, therefore providing the worst case on which to base the rating calculation. The maximum ambient temperature will vary for each site due to the different site characteristics. In order to estimate these values for the tool, where the data provided may be as little as 2 weeks' worth, the maximum ambient temperatures measured in the trial were used. This value was calculated for each building type, as shown in table 1 below.

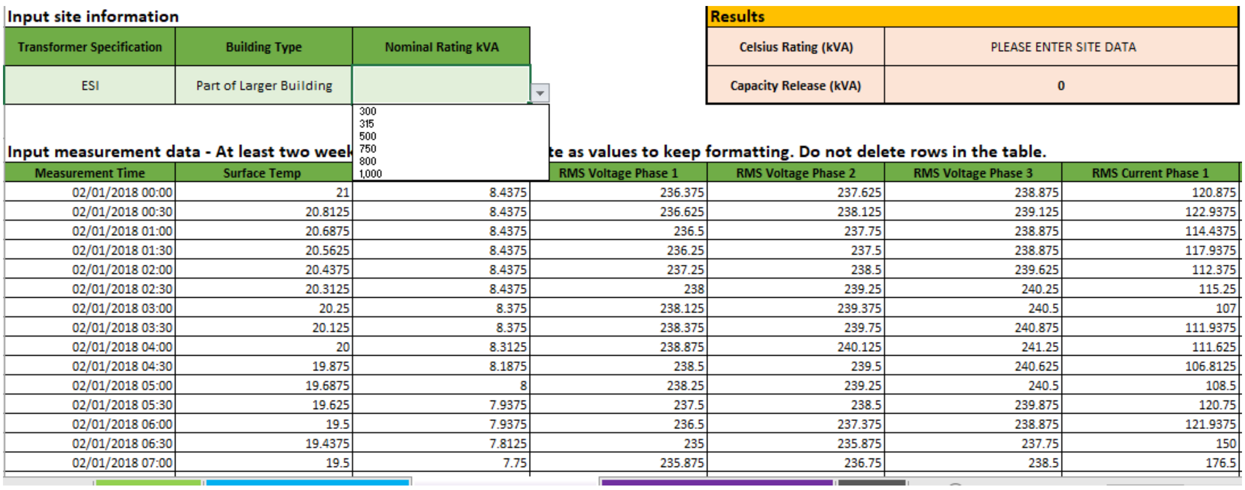
- **Outdoor sites only – Maximum weather temperature:** This is the maximum weather temperature over the course of the year, and therefore representing the worst case on which to base the rating calculation. As a result, the maximum weather temperature was calculated for outdoor sites using all of the data from the Celsius trial, and was estimated to be 33 ℃
- **Outdoor sites only – Minimum wind speed:** The is minimum wind speed throughout the year, which represents the worst case on which to estimate the Celsius Rating. In this case, wind speed was set to 0 m/s for each outdoor site.

Site Building Type	Maximum Ambient Temperature (℃)
Stone/Brick	34.25
Part of Larger Building	31.69
GRP	38.88

Table 1: Maximum ambient temperature for each building type category

The example below shows how the input is presented in the Celsius Ratings Tool. The user can use the drop-down menus to select the site information that is relevant to their site.

Finally, the user can enter half hourly measured data for at least 2 weeks, and the tool will generate an estimated Celsius rating and the potential capacity release. The user cannot enter a nominal rating of less than 300 kVA, as the results for smaller transformer sizes were inconclusive during the Celsius trial.


Input site information

Transformer Specification	Building Type	Nominal Rating kVA
ESI	Part of Larger Building	

300
315
500
750
800
1,000

Results

Celsius Rating (kVA)	PLEASE ENTER SITE DATA
Capacity Release (kVA)	0

Input measurement data - At least two week[...]te as values to keep formatting. Do not delete rows in the table.

Measurement Time	Surface Temp		RMS Voltage Phase 1	RMS Voltage Phase 2	RMS Voltage Phase 3	RMS Current Phase 1
02/01/2018 00:00	21	8.4375	236.375	237.625	238.875	120.875
02/01/2018 00:30	20.8125	8.4375	236.625	238.125	239.125	122.9375
02/01/2018 01:00	20.6875	8.4375	236.5	237.75	238.875	114.4375
02/01/2018 01:30	20.5625	8.4375	236.25	237.5	238.875	117.9375
02/01/2018 02:00	20.4375	8.4375	237.25	238.5	239.625	112.375
02/01/2018 02:30	20.3125	8.4375	238	239.25	240.25	115.25
02/01/2018 03:00	20.25	8.375	238.125	239.375	240.5	107
02/01/2018 03:30	20.125	8.375	238.375	239.75	240.875	111.9375
02/01/2018 04:00	20	8.3125	238.875	240.125	241.25	111.625
02/01/2018 04:30	19.875	8.1875	238.5	239.5	240.625	106.8125
02/01/2018 05:00	19.6875	8	238.25	239.25	240.5	108.5
02/01/2018 05:30	19.625	7.9375	237.5	238.5	239.875	120.75
02/01/2018 06:00	19.5	7.9375	236.5	237.375	238.875	121.9375
02/01/2018 06:30	19.4375	7.8125	235	235.875	237.75	150
02/01/2018 07:00	19.5	7.75	235.875	236.75	238.5	176.5

Figure 6: Example of how the input may look if appropriate data has been entered into the tool

Ricardo
Energy & Environment

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR
United Kingdom

t: +44 (0)1235 753000
e: enquiry@ricardo.com

ee.ricardo.com