# Smarter Suffolk Project

# Road Temperature Sensors

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# Contents

# 1 Executive Summary

Winter gritting is an essential aspect of winter highways maintenance, part of the legal duty of the highways authority to *"ensure that, as far as reasonably practicable, safe passage along a highway is not endangered by snow or ice."* Suffolk Highway's winter service plan draws on guidance from the National Winter Service Research Group's Practical Guides to ensure defensible good practice in undertaking these duties. Winter gritting involves the spread of sand and salt mix on approximately 50% of the county's roads in accordance with a treatment protocol matrix, and minimises ice formation on these roads. This is undertaken in accordance with a weather forecast provided by a specialist service based on data from twelve weather stations, and is currently implemented in four geographical domains.

This report investigates the potential to install road surface temperature sensors at a greater geographical frequency, to provide the local authority with additional information on road surface temperature, to inform winter gritting decisions on a more granular basis. The sensors investigated are "lower cost" than existing full weather stations, covering an order of magnitude price range. Five suppliers provided road surface temperature sensors to the project. The report details and investigates the data returned from the sensors, and makes conclusions and recommendations based on the data analysis.

It pulls together this information in a financial and business case assessment, and makes recommendations for use of increased granularity of road surface temperature measurements for winter gritting decision making.

Exploration with interviews, workshops and through analysis of the data gathered within this project highlighted the importance of reliable equipment and appropriate calibration.

Sensors communicated data in near-real time using different network communications technologies. The weather and road surface temperature sensors in this project used three different network solutions:

- Connection via mobile data with a SIM card in a hub attached to each device;
- Connection via Zigbee protocol to a street lighting supplier's own Zigbee network; this connection was found to rely on very close proximity to an active street lighting network with multiple street lighting nodes;
- Provision of LoRaWAN gateways (by the project) enabled re-transmission of signals from multiple devices, but presented challenges in provision of LoRaWAN network in locations of interest.

Sensors were provided by five suppliers:

- Elsys in-ground sensor, provided by Lucy Zodion; this is battery powered and communicates via LoRaWAN.
- CIMCON's own remote sensor; this is powered via the lighting column and communicates by cable to the node and then via Zigbee network.
- Libelium weather station with remote road surface temperature sensor, provided by SSE; this is powered via the lighting column and communicates by Zigbee network.
- Uniotec's own in-ground and remote sensors; this is battery powered and communicates via LoRaWAN.
- Vaisala DST111 sensor supplied by Telensa; this is powered via the lighting column and communicates by cable to the hub and then via mobile data.

Some other sensors were provided as hardware, but the data from them was not made available. These are also described in this report.

Data was acquired for assessment from the suppliers' dashboards as downloadable csv files, or by email from the suppliers:

Sensors were installed across Suffolk, for operation on an eight month to two year time frame. Installations were in Ipswich and Lowestoft, in locations selected to be on gritting routes, and at Adastral Park for a co-location comparison.

Sensor reliability was assessed as continuity of data. All sensor providers had a number of sensors that ceased to be operational during the trial, and gaps in data gathered of various lengths up to several months. Sensor unreliability was attributed to several factors, including communications networks, issues with devices and power connections, accidental damage or removal of sensors, expiry of licencing, and potentially other factors.

Calibration of sensors was found to be variable. To assess calibration, sensors were co-located at Adastral Park. These indicated increasing discrepancy in measured values through time, with time discrepancies and loss of sensitivity.

The business case for the use of in-fill road surface temperature sensors has been examined. At present, Suffolk County Council's weather forecast supplier accesses data from twelve in-county weather stations. They can offer increased granularity of service with provision of route-based forecasts. Discussions are recommended to see if increased provision of data will enable more accurate or more granular weather forecast provision. Further discussions with other authorities may explore future options to use in-fill data.

It is concluded that additional weather stations will be of use for multiple reasons, and increased road surface temperature sensors may be beneficial, when a path to use the data in decision-making has been identified.

# 2 Introduction

## 2.1 Introduction

This report discusses the potential for additional sensors for measuring road surface temperature to inform winter gritting decisions on highways.

The first section of this report describes winter gritting management, including both the existing decision process and the infrastructure used to inform and carry out the maintenance.

The second section describes and reviews commercially available remote sensors that can be used for road surface temperature monitoring with the intention of informing gritting management decisions. These are offered by different companies, using Internet-of-Things communication technologies to report road surface temperature (and, in some cases, other parameters) in real-time. This report examines the function of these sensors, and the data they provide. Several of these sensors have been installed and run at locations across Suffolk.

The third section compares these sensors. Preliminary evaluation is made based on initial observations.

The fourth section analyses data from these sensors, making comparisons between different models, and drawing recommendations and conclusions based on identified issues.

This fifth section includes how the data the sensors provide could potentially inform winter maintenance decision-making, and an initial consideration of their potential for incorporation into decision models. It assesses the financial, social and business case inputs for increased granularity of road surface temperature sensors across Suffolk.

The sixth section provides overall conclusions and recommendations.

## 2.2 Process and structure

Winter gritting decisions are informed by a specialist commercial weather forecasting service. In cold weather, salt is spread on roads to prevent the formation of ice, or remove ice that has formed. In lower temperatures, grit may also be added to increase grip on ice that has formed. In Suffolk, the Winter Service is delivered from eight depots (Suffolk Highways, 2019) where salt and grit are stocked and stored in large quantities prior to winter, and may be re-stocked during the winter if necessary. Salt (with or without grit) is spread from gritters operating from these depots, typically in the evening and early morning along specified roads.

Details of the plans in Suffolk are described in Section 2.3.3.

## 2.3 Winter Management

### 2.3.1 Purpose

Suffolk Highways, on behalf of Suffolk County Council, manage their winter service as part of highways maintenance. Their annual plan is published online for public access, and details the processes they will carry out to meet their "*legal duty to ensure that, as far as reasonably practicable, safe passage along a highway is not endangered by snow or ice.*" (Suffolk

Highways, 2019). The plan notes that *"winter service ... has a finite resource and this must be taken into consideration when defining the level of service and treatment timings."* The Suffolk Highways Winter Service Plan draws on guidance from the National Winter Service Research Group's Practical Guide, and its predecessor, the UK Roads Liaison Group's national code "Well Managed Highway Infrastructure".

This report was prepared with reference to Suffolk Highways Winter Service Plans 2018-2019 and 2019-2020 (Suffolk Highways, 2018 and Suffolk Highways, 2019).

### 2.3.2 Management software

Suffolk Highways receive specialist daily and updated forecasts from a commercial weather forecaster, formerly MeteoGroup RoadMaster now merged with DTN, and described as the largest private weather business. These forecasts are based on the network of a dozen weather stations on highways across the county, together with information from a wider range of sources.

Vasiala Manager Software is used to access the forecast information, and to communicate the planned actions. Salt usage during each run is measured on depot weighbridge, and manually input by the supervisor. Vehicle routing and movement is relayed and recorded by Exactrak. This information is stored for future reference.

### 2.3.3 Suffolk County Council

Suffolk County Council's Winter Service Plan details the winter treatment of 50% of the county's roads (excluding three trunk roads of strategic importance that are the responsibility of Highways England), with two priority bandings depending on road usage. Priority 1 routes are approximately 1259 miles (2015km) long and priority 2 routes cover approximately 843 miles (1349km). Selection and prioritisation of routes is based on network classification and service provision.

Roads are treated in accordance with a treatment matrix that is dependent on temperature (above and below 1°C) and presence and timing of rain, fog, snow or hoar frost (ice formed by the freezing of water vapour under specific cooling conditions), with adaptations based on local knowledge and experience.

The Winter Service Plan sets out arrangements for winter maintenance during the Winter risk period, from October to April inclusive. Timeframes for gritting are defined with respect to the predicted timing of the hazard, and with consideration of periods of busier road usage.

Treatment Actions are determined by the Countywide Decision Maker, with multiple officers within the Council having specific responsibilities across the planning and delivery of the service.

From the 2018-2019 season, Suffolk has been divided into four geographical domains (West Suffolk, Central Suffolk, Ipswich, Coastal) to enable winter treatment decisions to be made for each specific domain, and avoid gritting across the entire county on each occasion.

### 2.3.4 Management Opportunities and Challenges

Winter management presents some challenges and opportunities. It is essential to treat and manage roads safely, but unnecessary gritting has cost and environmental impact. The introduction of geographical domain-based decisions has reduced gritting, enabling decisions to be made for one or more of the four domains across the county. Increased granularity, whether on a domain basis or along specific routes, may support this move towards increasingly targeted gritting.

Literature research on the use of sensors has been characterised by the remark that *“the emerging Internet of Things is starting to provide the enabling technology to saturate our infrastructure with low-cost sensors”* (Chapman and Bell, 2018). They refer to improvements made in selective salting for winter road maintenance treating the coldest sections of road (Handa, Chapman and Yao, 2006) which suggested savings of 10% in terms of distance travelled.

Chapman and Bell also refer to work done to improve road weather forecasting (Hammond, Chapman and Thornes, 2010), but remark that improved availability of affordable sensors would enable monitoring at higher spatial resolution. They postulate that if new “*approaches can improve confidence in these forecasts, then selective salting (where treatment is only actioned on sections forecast to freeze) would result in large cost savings … a paucity of observations remains a significant barrier to implementation.”*

Chapman and Bell (2018) described their laboratory testing in a climate chamber as they developed their device, to ensure accuracy of developed hardware is sufficient. They comment that “*low-cost devices are essentially consumables, and a rotational deployment–calibration strategy could be an option here.”* They explore the idea that increased resolution of observations will have an impact on forecasting and nowcasting products.

## 2.4 Literature Review: environmental impact of winter gritting

The potential for environmental impact of winter gritting, salt and de-icing agents is widely acknowledged. The Environment Agency (1990) in their now-withdrawn Pollution Prevention Guide 10: Highways Depots commented with respect of larger salt storage at depots: *“The environmental impact of rock salt is well documented …. because of the large quantities stored, there is the risk of pollution of rivers and groundwaters, due to run-off from rock salt stockpiles. This can come from both the salt itself and the sodium ferrocyanide anti-caking agent which is often added to it. Even when a stockpile is removed, the ground beneath it may remain contaminated.”* The guide recommended covered and lined salt storage areas. Uncovered salt storage leads to salt loss and potential pollution. Whilst this guidance is focused on salt stores in highways depots, the negative environmental impact is also relevant for spread salt.

The key legislation relevant to this impact is the 1990 Environment Protection Act to prevent pollution of ‘Controlled Waters’ (surface water and groundwater).

Environmental concerns in addition to impact on surface water and groundwater have been identified: these concerns include impact on vegetation (such as described by Ordóñez-Barona *et al.* (2018)), and impact on insects in aquatic ecosystems (such as described by Jackson and Funk (2019)). These concerns have also been raised in newspapers (Hickman, 2010).

The National Winter Service Research Group (2021) guide is focused on local authority treatment. Their Practical Guidance Documents include reference to potential environmental impact in Sections 3, 4 and 5, (National Winter Service Research Group, 2019a, 2019b, 2020a), predominantly in the context of storage management.

Vignisdottir *et al.* (2019) reviewed literature on environmental impacts of winter road maintenance from spread salt. They found that articles focused on local impact, with little focus on global impact. The main local effect researched has been on water in the area, and they identified two articles on biodiversity. Local impact reported includes: air quality; changes or harm to vegetation and soils, and watersheds.

A study of the potential impact of salt from highway winter gritting / salting in the UK Midlands suggests likely significant impact on a local stream, and that highways salt is a potential cause of increased salinity observed in a pumped water supply well (Rivett *et al.*, 2016). They describe the typical UK winter weather conditions, legal requirements and salting methods, resulting in relatively high salt spreading rates. International studies also discuss impact on surface water, groundwater, vegetation and both terrestrial and aquatic ecosystems from road salt (Cooper, Mayer and Faulkner, 2014; Jamshidi, Goodarzi and Razmara, 2020).

## 2.5 Technologies and sensors

Different methods of acquiring road temperature measurements have been explored. These cover four technology areas:

- Road weather solution with in-county weather stations
- Column-mounted remote temperature sensors
- In-ground road temperature sensors
- On-vehicle thermal sensing devices

These technologies offer different challenges and benefits. The potential for residual salt measurement is also being considered.

Each technology is discussed in the following subsections. Specific column-mounted and in-ground sensors are discussed in Section 2.

### 2.5.1 Road weather solution with in-county weather stations

Currently, Suffolk County Council use a winter road weather solution provided by Meteogroup RoadMaster: "*physical and statistical modelling techniques combine the best available weather models with data collected from road weather information stations (RWIS), historical predictions, and records of actual weather conditions to generate the most precise location-specific forecasts available*" (MeteoGroup, 2019). In Suffolk, data is gathered from a county-wide network of twelve weather stations mostly owned by Suffolk County Council, with some accessed through reciprocal sharing arrangements with Highways England and with neighbouring local authorities.

The process to implement winter treatment is made by a Countywide Decision Maker, assisted by Support Decision Makers (Suffolk Highways, 2018, 2019). Treatment decisions are made daily *"based on the weather forecast received by 12.00"* and reviewed *"following the 18.00 evening forecast update"*. Support Decision Makers review forecasts and observations from weather stations for treatments during the night. Forecasts are provided three times during each day (06:00, 12:00 and 18:00).

Geographical variations across the county are mapped in thermal maps, refreshed in 2016, viewed in the county's Vaisala Manager system. Based on these maps, the county is managed in four geographical domains, each corresponding to a specific forecast site. Thermal maps are not currently applied in the decision-making process while *"further work is underway to explore* [their] *use in the decision-making process."*

### 2.5.2 Column-mounted remote temperature sensors

Column mounted infra-red sensors measure infrared radiation emitted by the surface. Some use battery power, and some need powering from lighting columns. On-column infra-red sensors from several manufacturers are being trialled across the county.
One advantage of infrared thermometry over in-ground contact sensors for this use-case is the non-invasive installation, minimising expense and disruption of groundworks, and concerns regarding ongoing road maintenance whilst maintaining the longevity and integrity of ground-installed sensors.

There appear to be benefits and disbenefits in using IR sensors over contact sensors in terms of the accuracy and reliability of the measurements obtained in these ways. These comparisons will be investigated further through additional literature review and comparison of data collected within this trial. Initial literature review findings are summarised in this report.

*"Surface temperature readings from IR sensors* [have been found to be] *more reliable than data retrieved from traditional surface-mounted sensors during wet, snowy, or icy road conditions"*(Jonsson and Riehm, 2012). They found that ground temperature correlated well with the infrared temperature measurements during dry weather, but that during weather changes, the IR temperature measurements correlated better with air temperature than ground temperature. They noted poor correlation between ground temperature measurements and IR temperature measurements when the road was wet, icy or snowy, due to "*the coverage of the ground temperature sensor at 2 mm by water, ice, or snow* [which] *will act as insulators in relation to the road surface".*

Jonsson and Riehm (2012) also noted that *"differences* [in temperature distribution] *can be observed during changes in the weather. Although there are only minor temperature differences in a road section, they may cause varying road conditions, especially when the road is wet and close to the pavement fluid freezing point"* They concluded that "*An infrared thermometer will be able to detect a sudden reduction in road surface temperature sooner than that of a road-installed sensor and will thus be able to provide an early warning in relation to a critical icing situation. This means that utilizing IR temperature measurements for surface temperature measurements will provide a more precise indication of heat flow compared to that involving the use of traditional surface-mounted temperature probes."*

### 2.5.3 In-ground road temperature sensors

In-ground road temperature sensors from a number of manufacturers and suppliers are being trialled. In-ground sensors require ground-engineering for installation (attaching the sensor to a network communications module, and power), therefore they are more disruptive to install, and to maintain during lifetime, with potential impact on future road maintenance, such as planing, to damage or remove equipment. In-ground sensors have been trialled in the small-scale site testbed lab, but not across the county.

Jonsson and Riehm (2012) noted that the shallow ground temperature sensor (2mm depth) would respond within minutes to changes in road surface temperature (due to the thermal conductivity of asphalt) but for a sensor at a greater depth of 0.3m "*the time for thermal energy to penetrate … is approximately one day. The implication of this is that the ground sensor at 0.3m may only be used as a measure of a stable road body temperature*".

### 2.5.4 On-vehicle thermal sensing devices

The potential of on-vehicle GPS-enabled road surface temperature mapping devices are being considered for their possible real-time on-road information gathering, but are not trialled within this project. These could potentially be mounted on gritting vehicles and inform grit application in real-time.

### 2.5.5 Other parameters

Road weather services use a range of other parameters for forecasting. These include humidity and air temperature to calculate dew point, and ground temperature at depth. These parameters are not considered within this report; some sensors provide some or all of these parameters.

### 2.5.6 Residual salt sensing

Reliable assessment of salt remaining on the road from previous gritting could enable recalculation of the salt required for the following gritting action. There is interest in the potential for sensing residual salt; this is being explored by desk-based research, but equipment trials are not currently planned. Potential for residual salt assessment could conceptually be from vehicle-mounted devices informing salt application in real time, or from in-road sensors informing pre-application planning.

At present, the Suffolk County Council Winter Service Plan states *"residual salt from previous operations can reduce the spread rates required to prevent frost/ice formation. Residual salt levels across the network are notoriously difficult to measure accurately and this issue is still very much in focus nationally as an area for ongoing and future research. Residual salt is not considered in the decision-making process in Suffolk."*

### 2.5.7 Assessment and evaluation

Investigation of the potential for road surface temperature sensors to support winter gritting management has included exploration of:

- How data from sensors is captured and presented in existing management software;
- Opportunities to trial and compare a number of systems in different areas;
- Assessing sensor function: information, reliability, issues;
- Informing the business case for investment in these products.

# 3 Specific sensors

## 3.1 Introduction

Road surface temperature sensors trialled within this project are considered in this report and are detailed below. This includes discussion of how the sensors function, how the suppliers provide information, and how they operate. Specific terminology used in this section, such as ‘thermopile’ and ‘contactless thermometry’, matches the terminology used by the manufacturers in their product descriptions.

### 3.1.1 Communications networks

The sensors communicate with online dashboards via Internet-of-Things type technologies. The sensors assessed use different communications technologies, which include:

- 3GPP mobile services, enabling access where mobile network coverage is available;
- Zigbee protocol communication utilising mesh networks created for street lighting;
- LoraWAN technology, requiring deployment of accessible LoRaWAN gateways.

Networks for connected places and smart city communication across the Smarter Suffolk Project have been discussed in detail in a separate project report (Steventon, 2021). The accessibility of a communication network is integral to the appropriate selection of air quality sensor hardware.

## 3.2 Uniotec column-mounted sensor

### 3.2.1 Introduction

Uniotec are a small sensor, data and prototyping company based in Norfolk, who have designed and supplied a range of Internet-of-Things sensors to Norfolk County Council and other public sector clients. Their earliest sensors were their road surface temperature sensors, which have been considered in the Suffolk County Council trial. These are at a lower price point than other sensors considered within the trial, which would make them more affordable for larger deployments and potentially easier to support a business case.

### 3.2.2 Sensor hardware

The Uniotec road temperature sensor has been developed by themselves, and uses a Melexis MLX90614 infra-red thermopile. The data sheet for the sensor and for the component sensor are included in the digital archive. The sensor is described as “factory calibrated”, and states 0.5°C accuracy between 0°C and 50°C, and 1°C accuracy from -40°C up to but not including 0°C.

The sensor is pictured in Figure 1. Its dimensions are approximately 105mm x 80mm x 55mm and it is mounted with a metal mounting bracket and screw band to attach to the column.

*Figure 1: Uniotec on-column road surface temperature sensor, image from Michael Price, Uniotec, 16/12/2019*

The angle to the road surface can be adjusted during mounting, and requires a clear view of the road surface.

The sensor does not currently state an IP rating.

The sensor uses a Lithium Thionyl Chloride battery, and makes no claims regarding battery life.

### 3.2.3 Sensor communication

The Uniotec sensor is a LoRaWAN v1.0 Class A device. Uniotec state that they can connect to a client owned network or other available networks such as The Things Network, which they have accessed with other councils. They have been used with Kerlink LoRa network (server, gateways and management centre) provided by BT research within the Smarter Suffolk project. LoRaWAN connectivity would require coverage from a LoRa network to communicate with the device.

The sensor does not currently support any other network technologies.

### 3.2.4 Approvals, standards and compliance

Uniotec do not currently specify any approvals, standards or other compliance for their road surface temperature sensor.

### 3.2.5 Sensor dashboard and data

Uniotec have developed a usable online dashboard with interactive visualisations and downloadable data. This shows locations of sensors, last connection, and temperature and battery voltages at that time, and data for any time period is downloadable as a CSV file. The same dashboard is used for their in-ground temperature sensors as their on-column temperature sensors.

Datetimes for the downloaded data are in ISO 8601 format.

## 3.3 Uniotec in-ground sensor

### 3.3.1 Introduction

As described in section 3.2, Uniotec are a small sensor, data and prototyping company based in Norfolk, who have designed and supplied a range of Internet-of-Things sensors to Norfolk County Council and other public body clients. Their earliest sensors were their road surface temperature sensors, which have been considered in the Suffolk County Council trial. These are at a lower price point than other sensors considered within the trial, which would make them more affordable for larger deployments and potentially easier to support a business case.

### 3.3.2 Sensor hardware

The Uniotec road temperature sensor has been developed by themselves, and uses a Dallas Maxim DS18B20 digital thermometer. The data sheet for the specific sensor and component sensor are included in the digital archive. They state 0.5°C accuracy between -10°C and 85°C, and 1°C accuracy from -30°C up to but not including -10°C. This sensor is based on the same DS18B20 digital thermometer contact sensor as the one manufactured by Elsys and supplied by Lucy Zodion (described in Section 3.6).

The column-mounted device part of the sensor is pictured in Figure 2. Its dimensions are approximately 105mm x 80mm x 55mm.

*Figure 2: Uniotec in-ground road surface temperature sensor, image from Michael Price, Uniotec, 16/12/2019*

The temperature probe is installed in a slot cut into the road surface, with 10m of cable provided to connect to the transmitter unit, which is onto a nearby column with cable ties . The angle to the road surface can be adjusted during mounting.

The sensor does not currently state an IP rating.

The sensor uses a Lithium Thionyl Chloride battery, and makes no claims regarding battery life.

### 3.3.3 Sensor communication

The Uniotec sensor is a LoRaWAN v1.0 Class A device. Uniotec state that they can connect to a client owned network or other available networks such as The Things Network, which they have accessed with other councils. They have been used with Kerlink LoRa network (server, gateways and management centre) provided by BT research within the Smarter Suffolk project. LoRaWAN connectivity would require coverage from a LoRa network to communicate with the device.

The sensor does not support any other network technologies.

### 3.3.4 Approvals, standards and compliance

Uniotec do not currently specify any approvals, standards or other compliance for their road surface temperature sensors.

### 3.3.5 Sensor dashboard and data

Uniotec have developed a usable online dashboard with interactive visualisations and downloadable data. This shows locations of sensors, last connection, and temperature and battery voltages at that time, and data for any time period is downloadable as a CSV file. The same dashboard is used for their on-column temperature sensors as their in-ground temperature sensors.

Datetimes for the downloaded data are in ISO 8601 format.

## 3.4 WinterSense column-mounted sensor

### 3.4.1 Introduction

Lucy Zodion provided the WinterSense road surface temperature sensor to the Smarter Suffolk project as part of the smaller scale test bed trials at Adastral Park.

The WinterSense sensor was developed by University of Birmingham (Chapman and Bell, 2018) following over three years of accuracy trials to ensure fitness for purpose over the required temperature range (https://wintersense.com/sensor accessed 04/10/19).

Licencing rights for WinterSense were acquired in 2019 by Campbell Scientific, who are developing its hardware and data.

Changes to availability as part of this IPR acquisition mean that Lucy Zodion are now offering a different sensor for their wider deployment, and data from the WinterSense sensor was not made available. Product details here represent the sensor hardware supplied, and are no longer current.

### 3.4.2 Sensor hardware

The WinterSense road temperature sensor uses a contactless passive infra-red thermopile, and was developed within a research project at the University of Birmingham. The datasheet for this sensor is included in the digital archive. They state 1°C accuracy.

The sensor as supplied pictured in Figure 3. Its dimensions are approximately 120mm x 80mm x 55mm, and weighs 400g.

*Figure 3: WinterSense sensor (image from previous version of www.wintersense.com, since updated)*

The sensor is mounted using a stainless steel mounting bracket and band, with the angle adjusted during mounting. It should be located within 2 metres of the road between 3 and 5 meters high.

The sensor does not currently state an IP rating.

The sensor uses 2 x C cell (3V total) and states this battery capacity will last approximately 2 years with 5 minute sampling and 30 minute uploads (https://wintersense.com/sensor accessed 04/10/19).

### 3.4.3 Sensor communication

The WinterSense sensor trialled in the Smarter Suffolk project communicates with LoraWAN network technology. It requires Class C and multicast capabilities. They have been used with Kerlink LoRa network (server, gateways and management centre) provided by BT research within the Smarter Suffolk project. LoRaWAN connectivity would require coverage from a LoRa network to communicate with the device.

The sensor also offered versions operating on WiFi and SigFox platforms, in addition to the LoRaWAN version. Data logger and control product company Campbell Scientific acquired global licencing rights for WinterSense in May 2019, and have made changes to the hardware and cloud platforms. They ceased to offer the WiFi and LoRaWAN versions and currently are only offering the Sigfox platform option. Further updates will include a version communicating on NB-IoT.

This change in platforms has meant that the WinterSense sensor is no longer supplied by Lucy Zodion, who currently operate their Smart City offering on LoRaWAN platform only. They have therefore supplied other products on LoRaWAN platform to the Smarter Suffolk trial, and the WinterSense sensor has not been trialled on a wider deployment in Suffolk.

### 3.4.4 Approvals, standards and compliance

WinterSense did not specify any approvals, standards or other compliance for their road surface temperature sensors.

#### 3.4.5 Sensor dashboard and data

WinterSense offered a cloud-based platform with data visualisation and network management. Images are available on their website, but it has not been possible to trial this web interface. Campbell Scientific informed the project that they will eventually be migrating the Wintersense Cloud platform into Campbell Scientific's core cloud service offering during 2021 and were running the Wintersense platform in its current form in the meantime.

Within the Smarter Suffolk project, data from the WinterSense sensor was not able to be supplied and has not been assessed.

### 3.5 DecentLab column-mounted sensor

#### 3.5.1 Introduction

Lucy Zodion have provided the DecentLab DL-ITST infrared thermometer / surface temperature sensor to the Smarter Suffolk project, for trial in the Adastral Park test bed and for wider deployment across the county.

DecentLab are a Swiss based company, founded in 2008, making monitoring products for infrastructure, environmental and smart city projects.

#### 3.5.2 Sensor hardware

The DecentLab sensor uses contactless infrared thermometry. The sensor data sheet is included in the digital archive. Measurement range is given as -40°C to 1030°C, and no accuracy or calibration is stated.

The sensor is pictured in Figure 4. Its dimensions are approximately 135mm x 81mm x 70mm, with a 1m cable to the sensor and a weight of 400g.

*Figure 4: DecentLab infrared sensor (image from www.decentlab.com 03/07/2020)*

The sensor installation instructions are based on four bolts, for mounting to a flat surface.

The sensor body is IP67 rated, indicating that it is dust-tight, with temporary protection against immersion (tested for 30 minutes at 1m water depth).

The sensor uses two C-type alkaline batteries, and DecentLab estimates its battery life as between 3.9 and over 15 years, depending on configuration. The product data sheet is included in the digital archive for this report.

Sampling and uploading intervals are configurable, with a 10 minute default.

### 3.5.3 Sensor communication

In common with all DecentLab products, the sensor communicates using LoRaWAN class A technology only, using Over the Air Authentication (OTAA), ABP, ADR and adaptive channel setup.

### 3.5.4 Approvals, standards and compliance

The sensor is declared to be CE compliant, including compliance with:

- Radio equipment directive (RED) 2014/53/EU
- Electromagnetic Compatability (EMC) Directive 2014/30/EU

### 3.5.5 Sensor dashboard and data

Data can be accessed via user’s own chosen infrastructure, or via DecentLab’s data storage and visualisation system. For this project, Lucy Zodion used the Kerlink LoRa network (server, gateways and management centre) provided by BT research within the Smarter Suffolk project, and is storing the data themselves.

Within the Smarter Suffolk project, data from the DecentLab sensor was not able to be supplied and has not been assessed.

## 3.6 Elsys sensor with in-ground temperature probe, supplied by Lucy Zodion

### 3.6.1 Introduction

Lucy Zodion have also provided the Elsys ELT-2 sensor, with DS18B20 temperature contact probe to the Smarter Suffolk project, for trial in the Adastral Park test. The in-ground sensor probe is the same DS18B20 digital thermometer contact sensor as used in the sensor manufactured by Uniotec (described in Section 3.3).

Elsys are a Swedish company, founded in 2005 as a university spin-off. They describe themselves as a provider of LoRaWAN sensors and devices, providing products for vehicles and logistics, and development services focused on wireless sensors and embedded systems.

### 3.6.2 Sensor hardware

The in-ground sensor is based on the same DS18B20 digital thermometer contact sensor as the sensor manufactured by Uniotec (described in Section 3.3). The data sheet for this sensor and for the Elsys device are included in the digital archive. Measurement range for this sensor is given as -55°C to 125°C, with 0.5°C accuracy claimed over the range -10°C to 85°C.

The ELT-2 unit and sensor probe are pictured in Figure 5. The dimensions of the ELT-2 unit are approximately 94mm x 59mm x 35mm, with cable to the sensor, and a weight of 60g excluding sensor and batteries.

*Figure 5: Eysys ELT-2 sensor and contact probe (images from https://www.elsys.se/en/ 08/07/2020)*

The sensor installation instructions are based on four bolts, for mounting to a flat surface. It can be tied to a column with appropriate straps.

The ELT-2 sensor body is IP67 rated, indicating that it is dust-tight, with temporary protection against immersion (tested for 30 minutes at 1m water depth). The probe does not state an IP rating.

The sensor uses one 3.6V AA Lithium battery, and Elsys estimates its battery life as over 10 years, depending on configuration and environment. The product data sheet is included in the digital archive for this report.

Sampling and uploading intervals are configurable.

### 3.6.3 Sensor communication

The Elsys sensor communicates using LoRaWAN class A or class C technology, using Over the Air Authentication (OTAA), ABP, ADR and adaptive channel setup.

### 3.6.4 Approvals, standards and compliance

The sensor is declared to be compliant with the following approvals and compliance. Abbreviations have been expanded and explained for this report:

- CE: European Economic Area certification for products confirming with relevant health, safety and environmental protection standards. This would be expected to include electrical safety, radio safety, radio emissions and accepted interference, safe use and operation.
- RoHS 2011/65/EU: also known as RoHS2, the European Union Restriction on Hazardous Substances directive 2. This restricts the use of specified substances, restricting the material content of new electronic equipment sold in the European Union, including proscribing the use of lead-based solders.
- WEEE 2012/19/EU: The European Union Waste Electrical and Electronic Equipment Directive sets collection, recycling and recovery targets for electrical goods.
- Class B digital device in accordance with Part 15 of the FCC Rules: The FCC rules are the United States Federal Communications Commission Declaration of

Conformity. This certifies that electromagnetic interference from the device is within approved limits.
- Industry Canada licence-exempt RSS standards: a Canadian Radio Standards Specification
- Directive 1999/5/EC: a European Directive not in force since 2016, related to conformity of radio and telecommunications equipment.

### 3.6.5 Sensor dashboard and data

Elsys do not provide dashboard or data visualisation. Data will be provided by Lucy Zodion for this project.

## 3.7 Vaisala DST111 sensor supplied by Telensa

### 3.7.1 Introduction

Telensa are a global provider of smart streetlighting and smart cities solutions, and are the incumbent street lighting control manager in Suffolk. Within the Smarter Suffolk project, they have provided the Vaisala DST111 Remote Surface Temperature Sensor, and would be able to provide or support other brands of sensors if desired.

Vaisala is a global company that produces products and services in environmental and industrial measurement. These include weather systems, including the weather stations that are implemented across Suffolk. Vaisala have other sensors that measure road surface temperature, and their suite of sensors is undergoing continuous development. Vaisala list a range of specific use cases and decision processes in trade articles dating from 2007 to 2016 linked on their website.

Vaisala describe their sensor measuring temperature measurement *"by measuring the infrared radiation emitted by the surface and applying intelligent signal processing"* (Vaisala, 2019b). Vaisala claim that the DST111 has "*unique correction for error caused by emissivity of the road surface, negating need for emissivity adjustment*" ((Vaisala, 2019a) (datasheet included in digital archive). They state that road surface emissivity in specific conditions (such as a cooling road with clear sky) can lead to error up to -3°C. In personal communication they have suggested that other models are less accurate (Telensa, 4/10/19). The sensor also measures humidity and atmospheric temperature. Reports referenced by Jonsson and Riehm (2012) investigated the Vaisala DST111 sensor, with *"One key finding* [being] *that the temperature readings between the IR sensor and the sensors installed in the pavement were comparable, even allowing for the fact that minor differences existed"*.

The measuring area depends on the height at which the sensor is installed. At a distance of 10m from the road surface for which the temperature is being measured, the measuring area is claimed to have a diameter of 150cm (Vaisala, 2019a)

### 3.7.2 Sensor hardware

The DST111 installed by smart streetlight operator Telensa is mounted on a sensor support arm, and connected to their in-house sensor hub to provide power, and data connectivity via an isolated RS-485 communications interface. The DST111 sensor is 125mm x 100mm x 320mm, and is pictured in Figure 6. The Telensa sensor hub is 280mm x 180mm x 60mm.

Figure 6: Vaisala DST111 sensor, image from www.vaisala,com

The sensor measurement range is given as between -40°C and +60°C.

The DST111 sensor does not specify an IP rating.
The Telensa sensor hub is IP65 rated, indicating that it is dust-tight and protected against water jets.

The sensor is powered via the sensor hub, from the lighting column power supply.

### 3.7.3 Sensor communication

The DST111 sensor communicates via an isolated RS-485 output to the Telensa UrbanIQ sensor hub. The Telensa sensor hub used cellular communications for backhaul. Telensa were not able to integrate their communications hub with their proprietary UNB communications technology operated for their existing streetlighting networks during the project.

### 3.7.4 Approvals, standards and compliance

Vaisala do not specify approvals, standards or other compliance on their product data sheet.

Telensa also do not specify approvals, standards or other compliance on their product data sheet.

### 3.7.5 Sensor dashboard and data

Telensa have developed an Urban IQ dashboard for their range of smart city options. This includes interactive visualisations and downloadable data. Currently (March 2022) the interactivity is limited, and constrains time periods visualised and downloaded to the past number of weeks, and by number of rows of data.

## 3.8 Libelium non-contact surface temperature measurement sensor, supplied by SSE

### 3.8.1 Introduction

Libelium design and manufacture a wide range of Internet of Things sensors. These are generally based on one of a selection of base units with optional probes. Libelium was provided to the Smarter Suffolk project by SSE Enterprise, as part of their Smart Cities offering.

One of the Libelium platforms is the Plug and Sense platform, which is described in this section.  The base station has sockets to add sensors from a wide selection, and offers a selection of options with pre-determined sensor selections. SSE provided a weather station comprising a Libelium base unit with a set of probes, including the Apogee SI-411 non-contact surface temperature probe to the Smarter Suffolk project.

Details have been obtained from Libelium's website (Libelium, no date b, no date c, no date a) and from the probe manufacturer (Apogee Instruments, no date). Libelium's Waspmote Plug and Sense Sensor guide, supplied by SEE, is included in the digital archive for this report.

### 3.8.2 Sensor hardware

The non-contact surface temperature measurement probe uses the Apogee SI-411 infrared radiometer sensor, measuring the electromagnetic radiation emitted by the surface, to provide the surface temperature remotely. Measurement range for this sensor is given as -45°C to 80°C, with 0.5°C accuracy claimed over the range, and 0.2°C over the range -20°C to 65°C. This sensor is provided with a calibration certificate in which the manufacturer ensures that the sensor has passed a calibration procedure with traceability to an accredited laboratory.

The unit and sensor probe are pictured in Figure 7. The dimensions of the probe are approximately 23 mm diameter x 60mm, with cable to the sensor, and a weight of 190g. The main unit body plus aerial has dimensions of 164 x 410 x 85mm, which does not include sensor probes. It weighs approximately 800g, excluding probes, an example unit with other probes is shown in Figure 7.

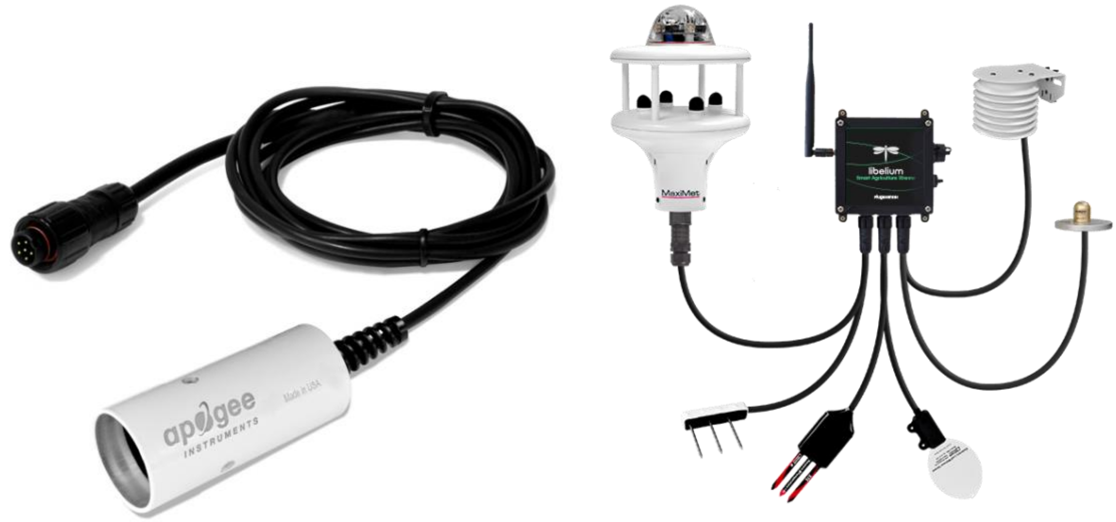


*Figure 7: Libelium sensor probe (images from https://development.libelium.com/smart-agriculture-xtreme-sensor-guide/sensors-probes)*

The sensor is installed on the column using an angle mounting bracket.

Sampling and uploading intervals are configurable.

### 3.8.3 Sensor communication

For the sensor installation for the Smarter Suffolk project, the supplier (SSE) operates their streetlighting network on a Zigbee mesh network, which is created by their lighting management system, with submaster gateways distributed across the area served. This Zigbee network is accessed by the Libelium sensors provided, for communications from these sensors.

The Libelium sensors can operate on a range of communications networks. These are described here as the list includes some that are less widely known.

- 802.15.4: the IEEE-maintained technical standard used by a selection of low-rate personal area networks, describing the physical layer and media access control. This standard is used by Zigbee.
- Zigbee: specifies high-level communications protocols for personal area networks based on IEEE 802.15.4. It has a range of up to around 100m line-of-sight to access a gateway or mesh network.
- 868 MHz: part of the licence-free radio spectrum in the EU, used in low power, wide area networks including LoRaWAN.
- 900MHz: part of the radio spectrum typically used by a range of industrial and scientific equipment.
- WiFi: standards-based wireless network protocol used for local area networks.
- 4G: broadband cellular network technology.
- Sigfox: an operator that provides low power wide area networks. They install and operate their own network, and claim wide coverage across England and Northern Ireland (less in Wales and Scotland).
- LoRaWAN: low power wide area network operating using the LoRa modulation in the licence-free spectrum (868MHz in the EU), with access provided by many different operators.

### 3.8.4 Approvals, standards and compliance

The Libelium sensors are CE compliant.
The main Plug and Sense unit is IP65 rated, with IK08 impact resistance.
Information on other certifications and standards has not been identified.

### 3.8.5 Sensor dashboard and data

For the Smarter Suffolk project, data was accessed from SSE’s Smart City dashboard, which provides visualisations and from which the data could be downloaded as CSV files.

## 3.9 CIMCON

### 3.9.1 Introduction

CIMCON provided their NearSky Road Temperature Monitoring Solution, using a remote, column-mounted sensor. These were installed at five locations in Lowestoft.

CIMCON are a street lighting company developing a smart city offering, now part of Quantela smart city platform.

### 3.9.2 Sensor hardware

The on-column remote sensor is described in their data sheet, included in the digital archive for this report. Measurement range for this sensor is given as -40°F to 150°F. (-40 to 65°C), with 2°F accuracy (approx. 1°C) claimed over the range 15°F to 100°F (9°C to 38°C).

The sensor probe and installation are pictured in Figure 8. The dimensions of the unit are not available, and a weight of 312g is given.

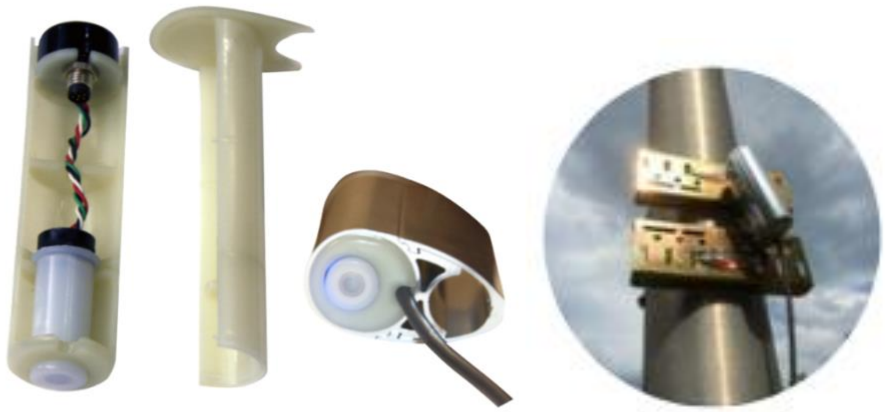


*Figure 8: CIMCON sensor (images from CIMCON Road Temperature Monitoring Solution datasheet)*

The sensor installation instructions are based on brackets on the column.

The sensor body is IPX7 rated, indicating that it is dust-tight, with temporary protection against immersion (tested for 30 minutes at 1m water depth).

The sensor is powered from the lighting column. The product data sheet is included in the digital archive for this report.

### 3.9.3 Sensor communication

The sensor communicates via cable to the lantern-mounted data processor and lighting controller, from there using ZigBee network to the CIMCON gateway for backhaul.
For the sensor installation for the Smarter Suffolk project, the supplier (CIMCON) operates their streetlighting network on a Zigbee mesh network, which is created by their lighting management system, with gateways distributed across the area served.

### 3.9.4 Approvals, standards and compliance

CIMCON do not specify approvals, standards or other compliance on their product data sheet.

### 3.9.5 Sensor dashboard and data

For the Smarter Suffolk project, data was accessed from CIMCON’s CityVibe dashboard, which provides visualisations and from which the data could be downloaded as CSV files.

## 3.10 Comparison and Evaluation

Details from the preceding section are summarised in Table 1, including parameters measured, size of the hardware, its IP rating, network requirements and data representation.

| | Uniotec | Uniotec | WinterSense | DecentLab | Elsys | Vaisala | Libelium | CIMCON |
|---|---|---|---|---|---|---|---|---|
| Type | Remote infra-red | In ground contact | Remote infra-red | Remote infra-red | In ground contact | Remote Infra-red | Remote Infra-red | Remote Infra-red |
| Temperature range | 0 to 50 °C;<br>-40 to <0°C[1] | -10 to 85°C;<br>-30 to <-10°C[1] | tbc | -40°C to 1030°C | -55°C to 125°C | -40°C to 60°C | -20 to 65 ºC<br>-40ºC to 80ºC | 9°C to 38°C<br>-40°C to 65°C |
| Accuracy | 0.5°C;<br>& 1°C[1] | 0.5°C;<br>& 1°C[1] | 1°C | Not stated | 0.5°C | 0.1°C | 0.2 ºC<br>& 0.5 ºC | 1°C<br>& not stated |
| Size (mm) | 105x80x55 | 105x80x55 | 120x80x55 | 135x81x70 | 94x59x35 | 125x100x 320 plus arm<br>Hub 280x180x60 | 23 mm diameter; 60 mm length | Not stated |
| IP rating | Not stated | Not stated | Not stated | IP67 | IP67 body<br>Probe not stated | Sensor not stated<br>Hub IP65 | Hub IP65 rated | IPX7 |
| Network | LoRaWAN | LoRaWAN | SigFox,<br>Updates to include NB-IoT | LoRaWAN | LoRaWAN | RS-485 interface to hub; hub via 3GPP or proprietary network | Zigbee used, others available | Cable to CIMCON Zigbee controller |
| Data access | Online dashboard | Online dashboard | Dashboard under development | No dashboard | No dashboard | Via Telensa UrbanIQ dashboard | Via SSE Smart City dashboard | Via CIMCON CityVibe dashboard |
| Battery type | Lithium Thionyl Chloride | Lithium Thionyl Chloride | 2 C cell (3V) | 2 C alkaline batteries | One 3.6V Lithium battery | Powered via lighting column | Powered via lighting column | Powered via lighting column |
| Cited lifespan | Not stated | Not stated | 2 years | 3.9 to 15 years | > 10 years | Not stated | Not stated | Not stated |

*Table 1 Comparative Summary of road temperature sensor hardware*

[1] *First accuracy stated applies to first temperature range stated. Second accuracy stated applies to second temperature range stated.*

### 3.10.1 Hardware: Ingress Protection Ratings, Size and physical structure

Most of the sensors do not have an IP rating, or do not have one for the complete unit. It would be considered that IP rating may be appropriate for wider provision into local authorities and other public sector clients.

The Vaisala sensor is connected via the Telensa hub, which adds a second item of hardware for communications and power. This makes a much larger combined installation than other sensors, which has led to some concerns and a complaint about visual impact in residential areas.

Other remote infra-red sensors are small items at height on columns, though some are connected by cable up the outside of the lighting column, adding to potential for damage, and visual impact.
In-ground sensors have additional complications of installation and impact on future road maintenance. They also have a cable running back to and up a column, also adding to potential for damage, and visual impact.

### 3.10.2 Measurement scope

The Uniotec remote sensor references a temperature range of 0°C to 50°C with accuracy of 0.5°C and a reduced accuracy of 1°C between -40°C and 0°C. CIMCON and WinterSense state an accuracy of 1°C across their main temperature range. It would be expected that reliable accuracy at temperatures below 0°C are relevant and important for winter use, and it is to be considered whether accuracy of 1°C is appropriate for potential use.

### 3.10.3 Communications

Sensors accessing mobile data services (ie GPRS/3G/4G or NB-IoT) would need to be installed in a location with adequate mobile coverage, but this would not be expected to provide a significant geographical constraint in most areas.
Sensors requiring LoRaWAN are dependent on the provision and maintenance of the LoRa gateways and network, which may be provided by local authority, sensor provider or a third party.
Sensors requiring SigFox connection (not used in this project) would require SigFox network coverage, which is currently good across most of Suffolk, with some areas not yet covered. However, the future of SigFox is unclear, as the company providing the service is currently in administrative receivership.

Sensors relying on local area networking, such as Zigbee, are reliant on the very close proximity of the mesh network. Suppliers using these technologies anticipate that network to be provided by streetlighting.

A separate, non-thematic report has been provided to discuss infrastructure communications options in more detail (Steventon, 2021).

# 4 Assessment of Data

## 4.1 Data Sources and Acquisition

Data from the installed sensors have been analysed, and are discussed in this section.

Sources for data used in the analysis are detailed in each subsection. In all but one case, data was downloaded from supplier dashboards, in a range of different formats. Data acquisition and manipulation proved an extremely time-consuming part of this project.

Data in the form of the acquired csv files was imported into and assessed using Python programming language in Integrated Development Environment Jupyter Notebooks, Anaconda Distribution. Two key libraries used for the data analysis were pandas to structure and manipulate data as dataframes and matplotlib for graphical presentations. Data were assessed for continuity of operation, as well as for the range and potential of the values gathered for use in highways gritting decision making.

## 4.2 Lucy Zodion Elsys sensor data

### 4.2.1 Installation and data access

Two Elsys sensors (described in Section 3.6) were installed in ground at Adastral Park, adjacent to Column 1 and Column 5. To install these, a slot was cut in the ground, the sensor and its connection cable placed, and the slot backfilled.

Data from these sensors was provided as csv files by email on request. Data from these sensors was not available on the Smarter Suffolk BT Data Exchange. It was not included on a supplier dashboard.

### 4.2.2 Reliability

Measurements were taken every ten minutes, and data has been provided for sixteen months. Reliability analysis indicates that there are 385 gaps of over ten minutes length during the sixteen month period, but most of these are only a single missing value. Analysis of length of gap (greater than 60 minutes) during the operational period has been undertaken, which indicates the following:

| Location | No of data points | No of gaps > 1 hrs | Longest gap in data |
|---|---|---|---|
| Column 1 | 70675 | 2 | 1:50 |
| Column 5 | 69427 | 4 | 2:00 |

*Table 2: Gaps in data during the 16 months analysed, Lucy Zodion Elsys sensors, Adastral Park*

The sensor communication is considered robust, with few significant gaps, regaining coverage quickly. In the context of other sensors assessed through the Smarter Suffolk project from other themes, the continuity of data can be considered comparatively reliable.

These two sensors operated throughout the 16 month period without ceasing operation.

### 4.2.3 Temperature data

Data from the two sensors was analysed for range of reported temperature. Four values of -1002 were reported by the sensor on column 5. As these are clearly erroneous, they have been removed from analysis.

Timeseries plots of this data for the complete period has been created (Figure 9). To illustrate the daily range, timeseries plots are also included for two separate months, February and August 2021 (Figure 10), each of which included data from both the sensors.

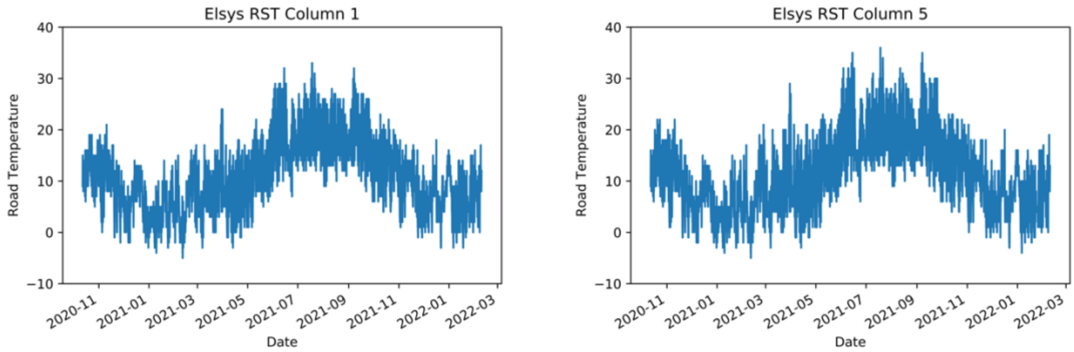


*Figure 9: Timeseries plots of temperature, Elsys Road Surface Temperature Sensors, Adastral Park*

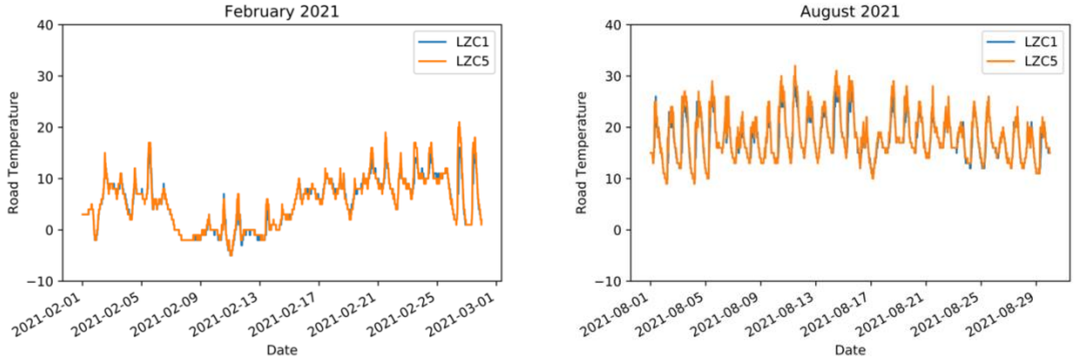


*Figure 10: Timeseries plots for selected months, Elsys Road Surface Temperature Sensors, Adastral Park*

Initial observations from these plots indicate the daily fluctuations and seasonal range. As it is the minimum value for each day that is of most interest for gritting decision making, data for each sensor has been examined based on statistics for each day. For each day, the minimum temperature level, together with the interquartile range (25% - 75%) and 10% to 90% range, has been calculated for the data. The results of this analysis are shown in Figure 11 and Figure 12.These figures show the variation in daily temperature range through the operational period, which varies with weather and seasonally. Comparisons of the daily minimum temperature measured by all these sensors is shown in Figure 13.

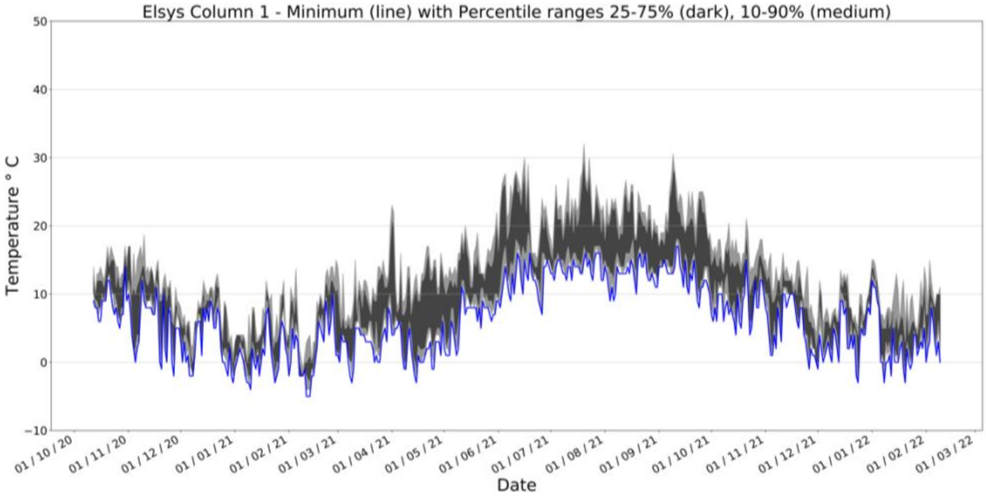


*Figure 11: Elsys RST sensors, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

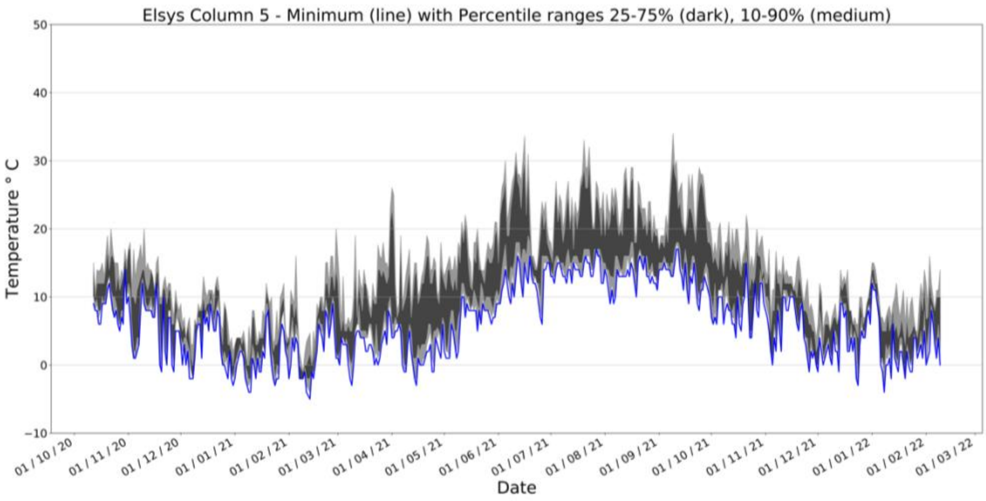


*Figure 12: Elsys RST sensors, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

To compare the data from the two sensors, the daily minimums have been plotted together in Figure 13. This shows a very close correspondence between measurements reported by these two in-ground sensors installed at nearby locations at Adastral Park.

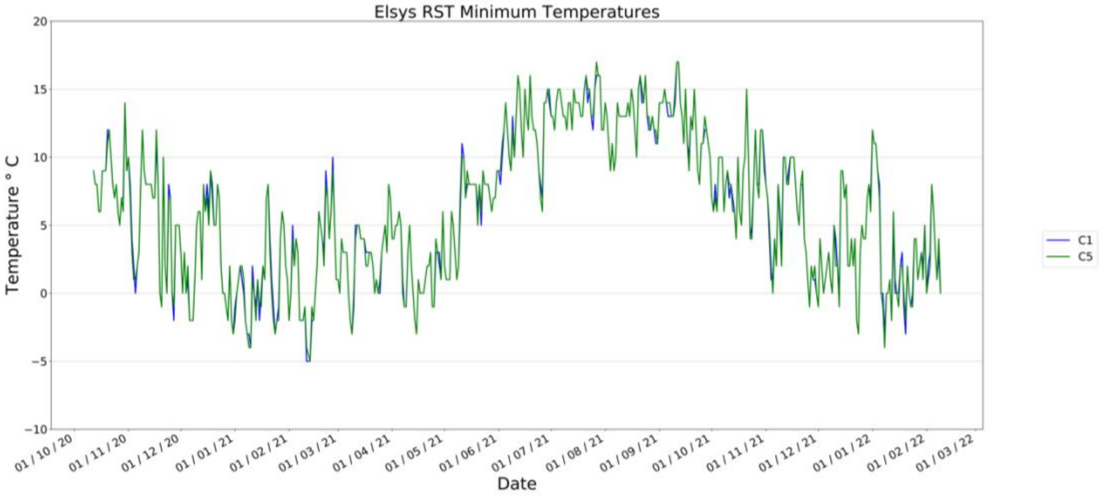


*Figure 13: Elsys RST sensors, minimum daily temperature*

### 4.2.4 Inspection of Installed Units

Installed units were visited for a visual inspection. As the units were installed high on lighting columns, close inspection was not possible. Photography was used to reveal visually installation arrangements and resilience of the devices (Figure 14).

Figure 14: Elsys Contact RST Sensors supplied by Lucy Zodion with in-ground installation (photo: H Steventon)

## 4.3 CIMCON sensor data

### 4.3.1 Installation and data access

Five CIMCON sensors (described in Section 3.9) were installed in selected locations in Lowestoft on street light columns (locations indicated in Figure 15).

Data from these sensors was not available on the Smarter Suffolk BT Data Exchange. Data from these sensors was provided as csv files downloaded from the supplier dashboard, CIMCON's StreetVibe platform. Selected dashboard screenshots are included in Figure 15.

Road and Air Temperatures Across NearSky360 locations

| NearSky360 Address | Road Temp in °C | Air Temp in °C |
|---|---|---|
| 1 Clover Way, Lowestoft NR32 4JS, UK | 5.28 | 6.06 |
| 10 Bentley Dr, Lowestoft NR32 4WA, UK | 5.43 | 6.74 |
| 254 Oulton Rd N, Lowestoft NR32 4QL, UK | 5.29 | 5.74 |
| 33 Field Grange, Lowestoft NR32 4XJ, UK | 5.18 | 5.72 |
| 67 Claydon Dr, Lowestoft NR32 3DZ, UK | 5.55 | 5.84 |

Lowest Road Temperature Across Locations
- 33 Field Grange, Lowestoft NR32 4XJ, UK with 5.18 °C
- 1 Clover Way, Lowestoft NR32 4JS, UK with 5.28 °C

Lowest Air Temperature Across Locations

Average of Road and Air Temperatures ( °C) by Hour

| NearSky360 Address | Timestamp | Road Temperature in °C | Air Temperature in °C |
|---|---|---|---|
| 1 Clover Way, Lowestoft NR32 4JS, UK | Mar 9, 2022 10am | 12.22 | 10.14 |
| 254 Oulton Rd N, Lowestoft NR32 4QL, UK | Mar 9, 2022 10am | 15.56 | 10.97 |
| 33 Field Grange, Lowestoft NR32 4XJ, UK | Mar 9, 2022 10am | 13.33 | 11.11 |
| 67 Claydon Dr, Lowestoft NR32 3DZ, UK | Mar 9, 2022 10am | 16.67 | 10.83 |
| 1 Clover Way, Lowestoft NR32 4JS, UK | Mar 9, 2022 9am | 8.89 | 9.72 |
| 254 Oulton Rd N, Lowestoft NR32 4QL, UK | Mar 9, 2022 9am | 11.11 | 11.25 |
| 33 Field Grange, Lowestoft NR32 4XJ, UK | Mar 9, 2022 9am | 7.78 | 9.86 |
| 67 Claydon Dr, Lowestoft NR32 3DZ, UK | Mar 9, 2022 9am | 13.33 | 9.44 |

Figure 15: CIMCON StreetVibe screenshots showing display of RST information

### 4.3.2 Reliability

Connection to the CIMCON Zigbee mesh network was initially challenging, and sensor locations were moved until successful connection was made. One of the five sensors (10 Bentley Drive) never connected reliably, with intermittent data return during the project and only 57 datapoints returned. Data for analysis has been taken from eventual locations only.

Measurements were taken every hour, and data has been analysed to 7 February 2022. Due to the connection challenges, the start date of operation has varied with the sensor, as indicated.

Reliability analysis indicates that there are multiple gaps in data (over an hour, which is the data interval) during the period of analysis. Analysis of length of gap (greater than 60 minutes) during the operational period has been undertaken, which indicates the following:

| Location | Start month | No of data points | No of gaps > 1 hrs | Average gap in data | Longest gap in data |
|---|---|---|---|---|---|
| 1 Clover Way | April 2021 | 6505 | 174 | 5:27 | 9 days 5:00 |
| 10 Bentley Drive | January 2021 | 62 | 57 | 6 days 14:02 | 20 days 14:00 |
| 254 Oulton Road N | February 2021 | 8156 | 213 | 3:28 | 1 day 2:00 |
| 33 Field Grange | January 2021 | 8997 | 168 | 3:51 | 3 days 13:00 |
| 67 Claydon Drive | July 2021 | 4964 | 171 | 2:34 | 22:00 |

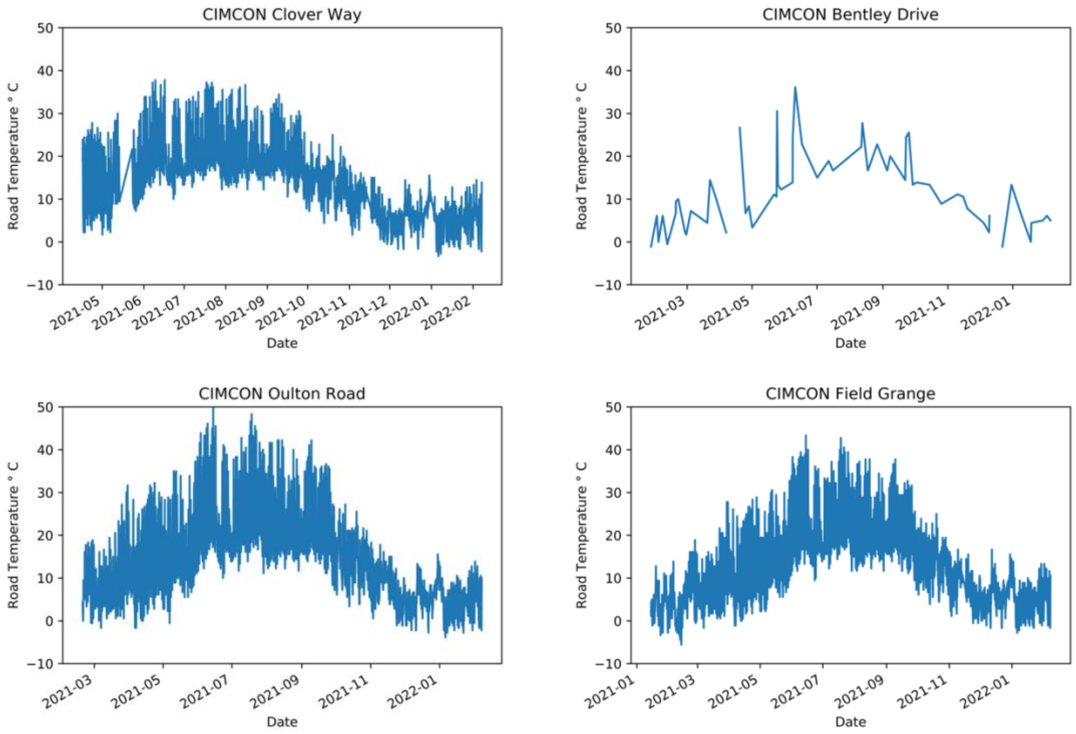
*Table 3: Gaps in data during the period analysed (up to 13 months), CIMCON RST sensors, Lowestoft*

The sensor communication is considered to have been variable. It is considered likely that areas with more dense and extensive ZigBee networks may provide more reliable communications networks for sensor data return.

### 4.3.3 Temperature data

Data from the five sensors was analysed for range of reported temperature.

Timeseries plots of this data for the complete period of analysis have been created (Figure 16). To illustrate the daily range, timeseries plots are also included for two separate months, February (Field Grange only, other sensors not operating) and August 2021 (all sensors, except Bentley Drive, which reported only 5 measurements in August) (Figure 17).



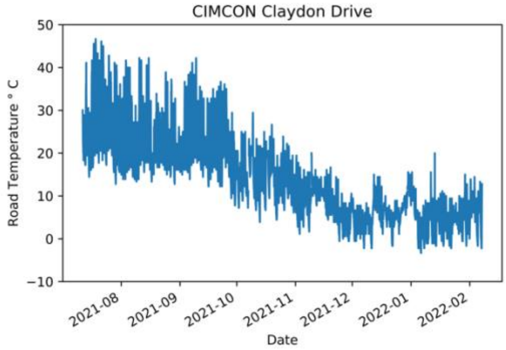


*Figure 16: Timeseries plots of temperature, CIMCON Road Surface Temperature Sensors, Lowestoft*

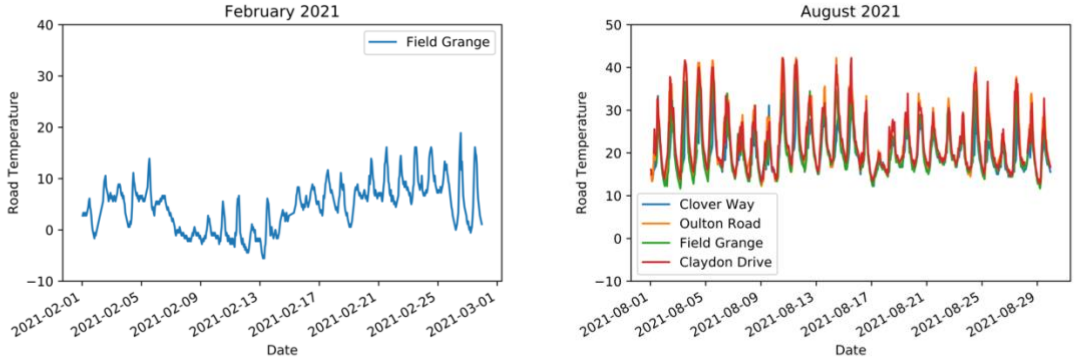


*Figure 17: Timeseries plots for selected months, CIMCON Road Surface Temperature Sensors, Lowestoft*

Initial observations from these plots indicate the daily fluctuations and seasonal range. As it is the minimum value for each day that is of most interest for gritting decision making, data for each sensor has been examined based on statistics for each day. For each day, the minimum temperature level, together with the interquartile range (25% - 75%) and 10% to 90% range, has been calculated for the data. The results of this analysis are shown in Figure 18 to Figure 21. These figures show the variation in daily temperature range through the operational period, which varies with weather and seasonally. Comparisons of the daily minimum temperature measured by all these sensors is shown in Figure 22.

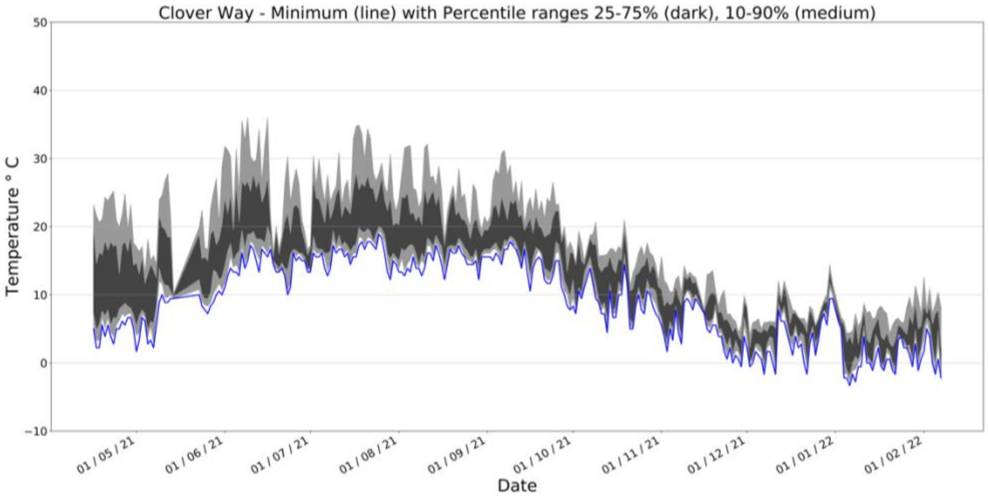


*Figure 18: CIMCON RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

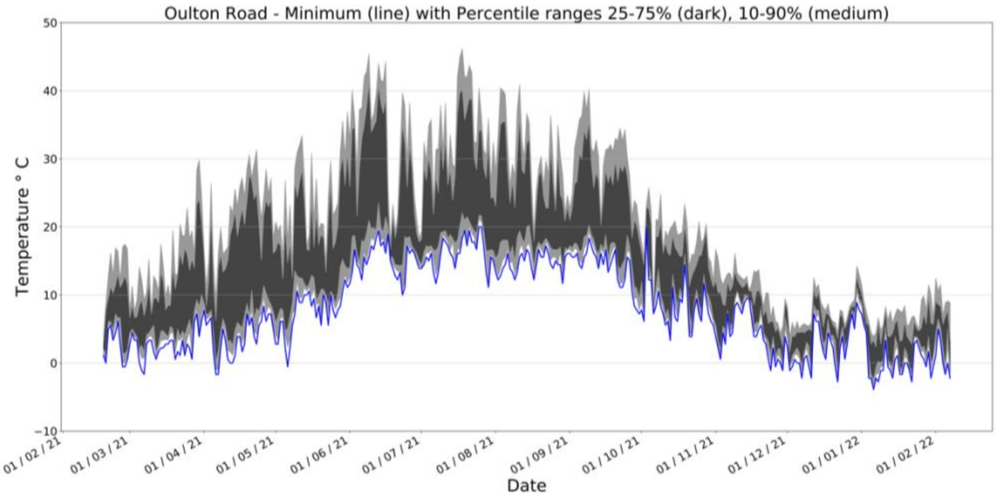


*Figure 19: CIMCON RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

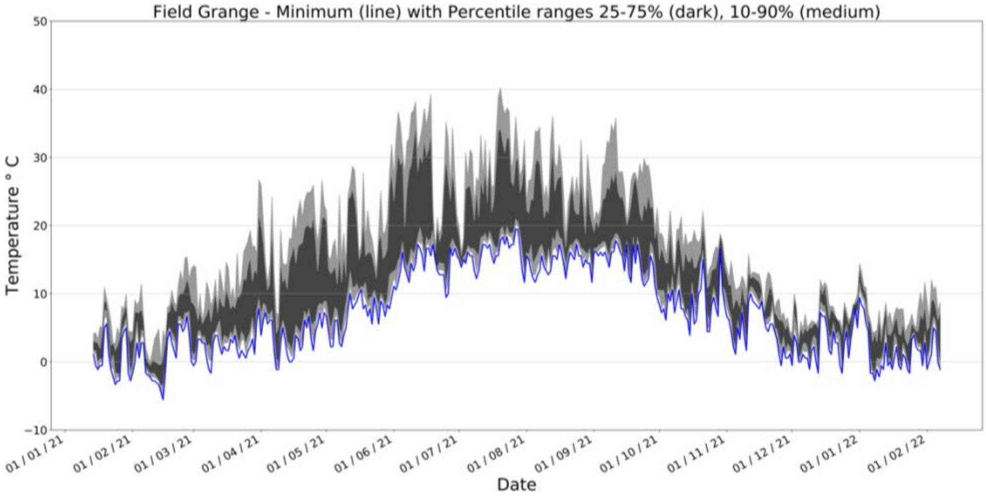


*Figure 20: CIMCON RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

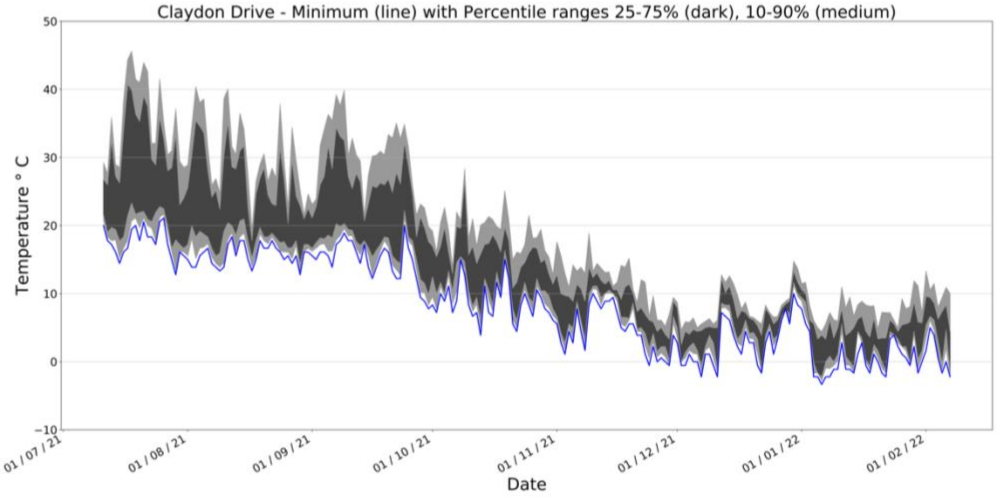


*Figure 21: CIMCON RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

To compare the data from the four sensors, the daily minimums have been plotted together in Figure 22. This shows a varying correspondence between measurements reported by these sensors installed at locations in Lowestoft. If an apparent date mismatch is allowed for, there are small differences in measured road surface temperature between these locations.

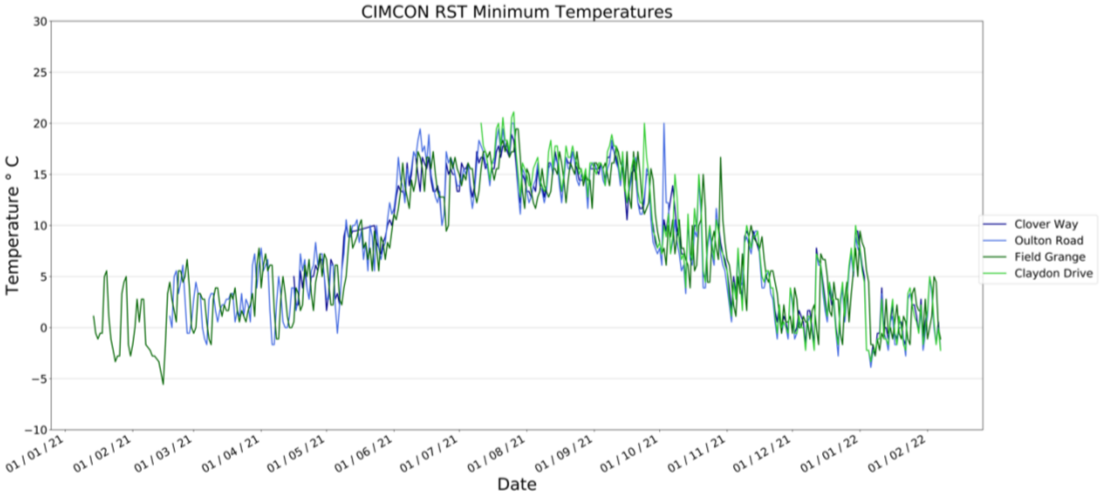


*Figure 22: CIMCON RST sensors, minimum daily temperature*

### 4.3.4 Inspection of Installed Unit

Installed units were visited for a visual inspection. As the units were installed high on lighting columns, close inspection was not possible. Photography was used to reveal visually installation arrangements and resilience of the devices (Figure 23).

*Figure 23: Remote RST Sensors supplied by CIMCON, photographed December 2021 (photo: H Steventon)*

## 4.4 SSE sensor data

### 4.4.1 Installation and data access

Five Libelium sensors supplied by SSE (described in Section 3.8) were installed in selected locations in Lowestoft and at Adastral Park on street light columns.

Data from these sensors was not available on the Smarter Suffolk BT Data Exchange. Data from these sensors was provided as csv files downloaded from the supplier dashboard, SSE's Mayflower Smart Cities platform. Selected dashboard screenshots are included in Figure 24.

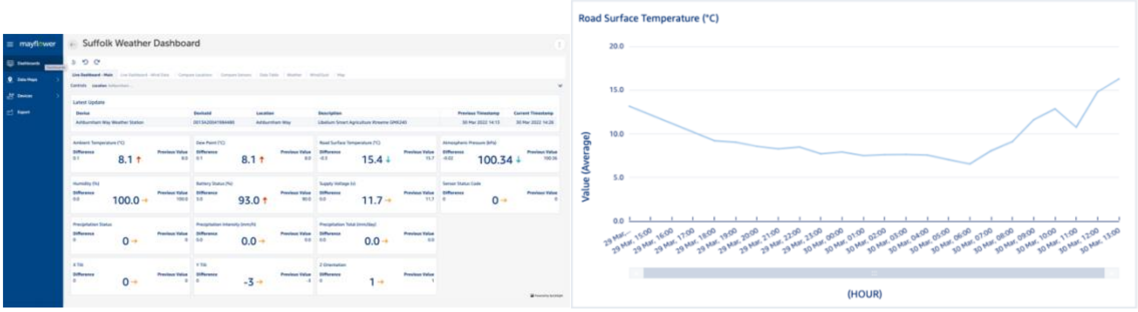


*Figure 24: SSE Street Vibe screenshots showing display of RST information*

### 4.4.2 Reliability

Connection was via the SSE Zigbee mesh. Locations were selected to enable communications network access.

Measurements were taken every hour, and data has been analysed from installation on 9 June 2021 to 7 February 2022.

Reliability analysis indicates that for most sensors there are few gaps in data (over an hour, which is the data interval) during the period of analysis. Analysis of length of gap (greater than 60 minutes) during the operational period has been undertaken, which indicates the following:

| Location | No of data points | No of gaps > 1 hr | Average gap in data | Longest gap in data |
|---|---|---|---|---|
| Ashburnham Way | 118750 | 6 | 3:00 | 4:00 |
| Bloodmoor Road | 119922 | 16 | 2:26 | 4:00 |
| Adastral Park | 88692 | 4 | 16 days, 15:00 | 36 days 14:00 |
| Lorne Park | 91446 | 191 | 3:29 | 1 day 4:00 |
| Ribblesdale Road | 120943 | 0 | n/a | n/a |

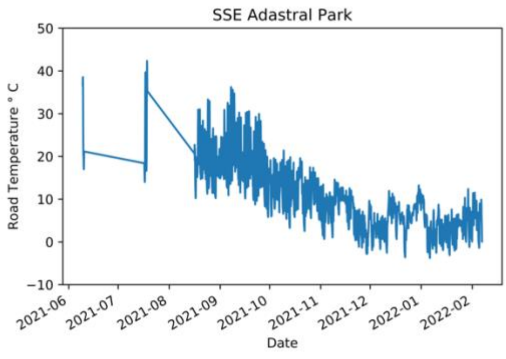
*Table 4: Gaps in data during the period analysed (approx. 8 months), SSE RST sensors, Lowestoft and Adastral Park*

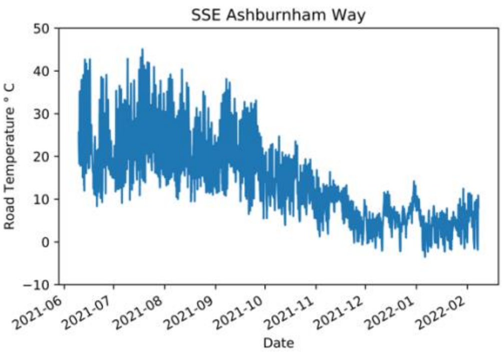
Power issues at Adastral Park requiring manual rebooting of equipment led to the longer periods of gaps at this location. One location in Lowestoft had multiple shorter gaps. The other three sensors had relatively few gaps, which were much shorter.  The sensor communication is considered to have been variable. It is considered likely that areas with more dense and extensive ZigBee networks may provide reliable communications networks for sensor data return.

### 4.4.3 Temperature data

Data from the five sensors was analysed for range of reported temperature.

Timeseries plots of this data for the complete period of analysis have been created (Figure 25). To illustrate the daily range, timeseries plots are also included for two separate months, August 2021 and February 2022 (Figure 26).





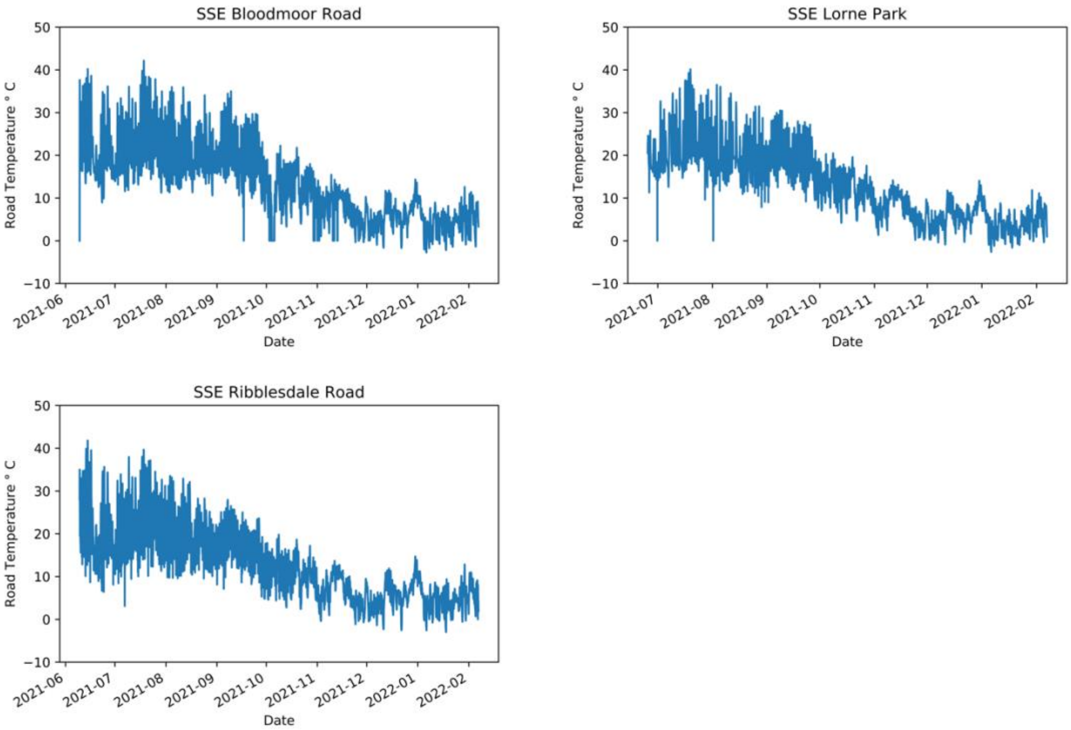


*Figure 25: Timeseries plots of temperature, SSE Road Surface Temperature Sensors, Lowestoft and Adastral Park*

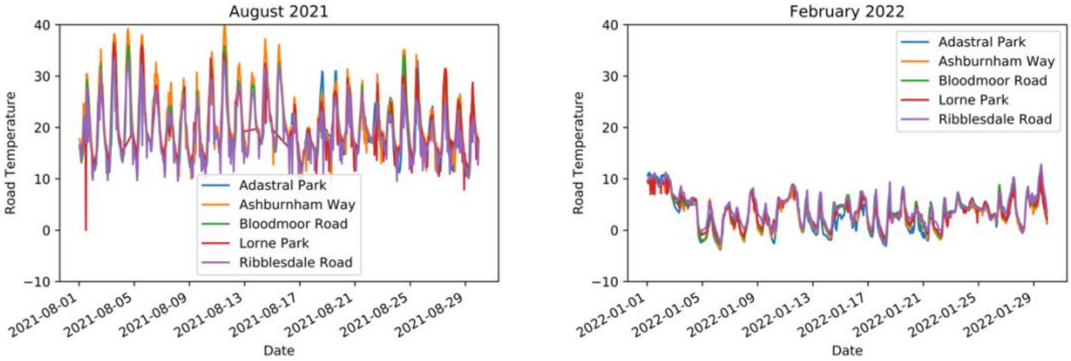


*Figure 26: Timeseries plots for selected months, SSE Road Surface Temperature Sensors, Lowestoft and Adastral Park*

Initial observations from these plots indicate the daily fluctuations and seasonal range. As it is the minimum value for each day that is of most interest for gritting decision making, data for each sensor has been examined based on statistics for each day. For each day, the minimum temperature level, together with the interquartile range (25% - 75%) and 10% to 90% range, has been calculated for the data. The results of this analysis are shown in Figure 27 to Figure 31. These figures show the variation in daily temperature range through the operational period, which varies with weather and seasonally. They also shown the longer non-operational periods observed in the sensor installed at Adastral Park. Comparisons of the daily minimum temperature measured by all these sensors is shown in Figure 32.

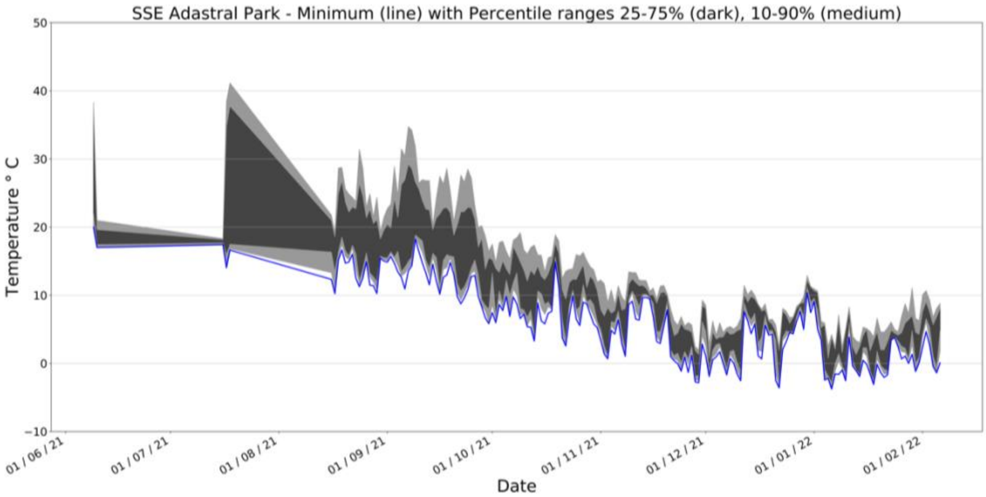


*Figure 27: SSE RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

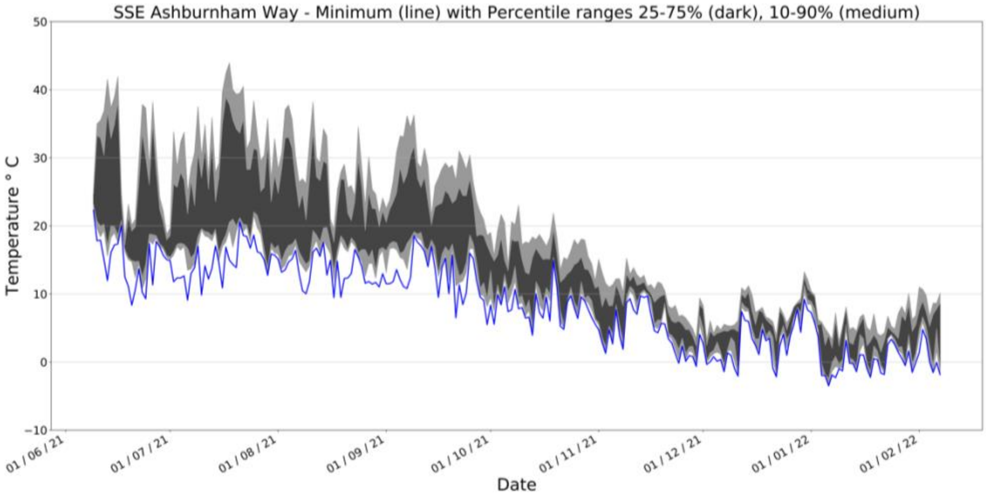


*Figure 28: SSE RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

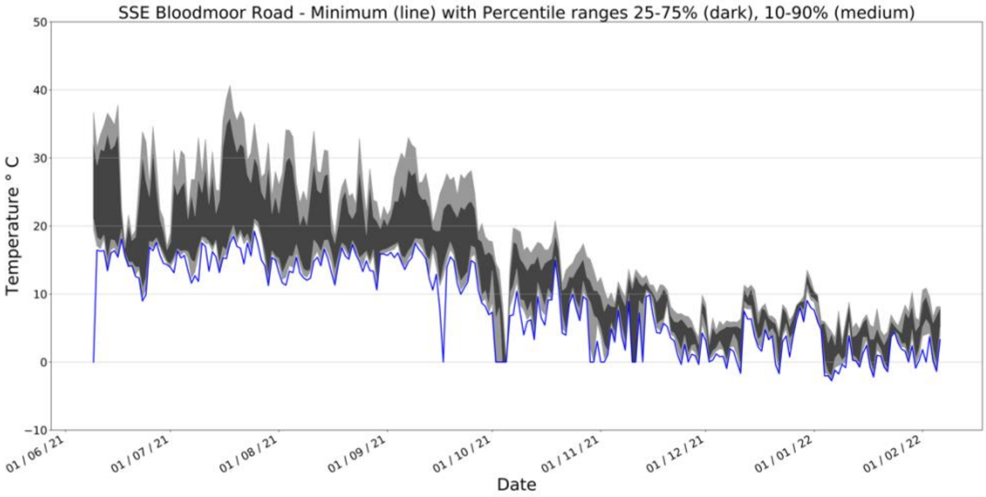


*Figure 29: SSE RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

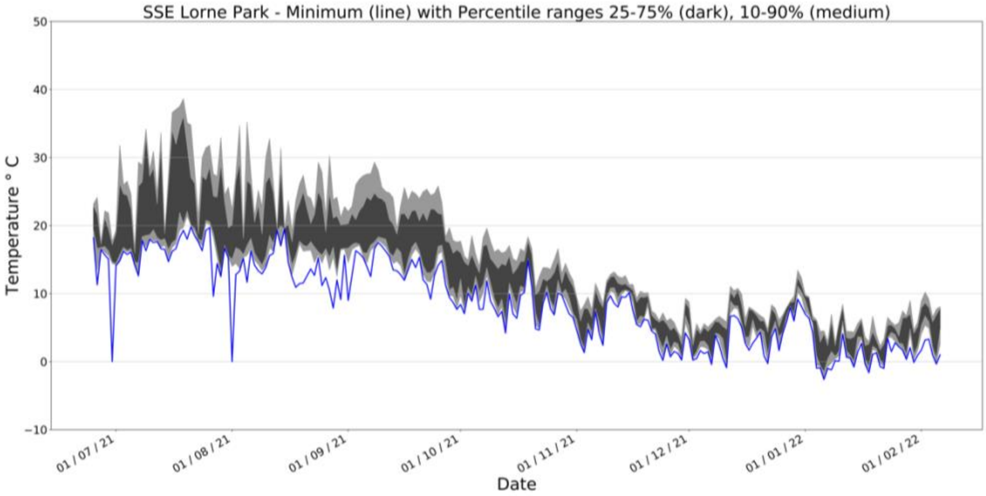


*Figure 30: SSE RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

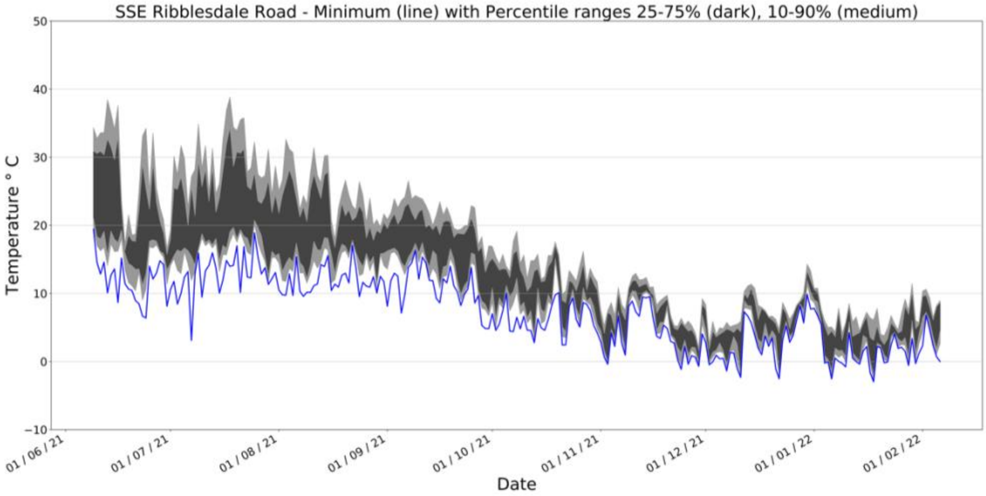


*Figure 31: SSE RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

To compare the data from the five sensors, the daily minimums have been plotted together in Figure 32. This shows a varying correspondence between measurements reported by these sensors installed at locations in Lowestoft, with small differences in measured road surface temperature between these locations. The plot also indicates the challenges of providing a ‘zero’ measurement for missing data, as discussed further in Section 6.2.2. Seven false zeros can be identified in this plot. Techniques to identify and remove these data points should be applied.

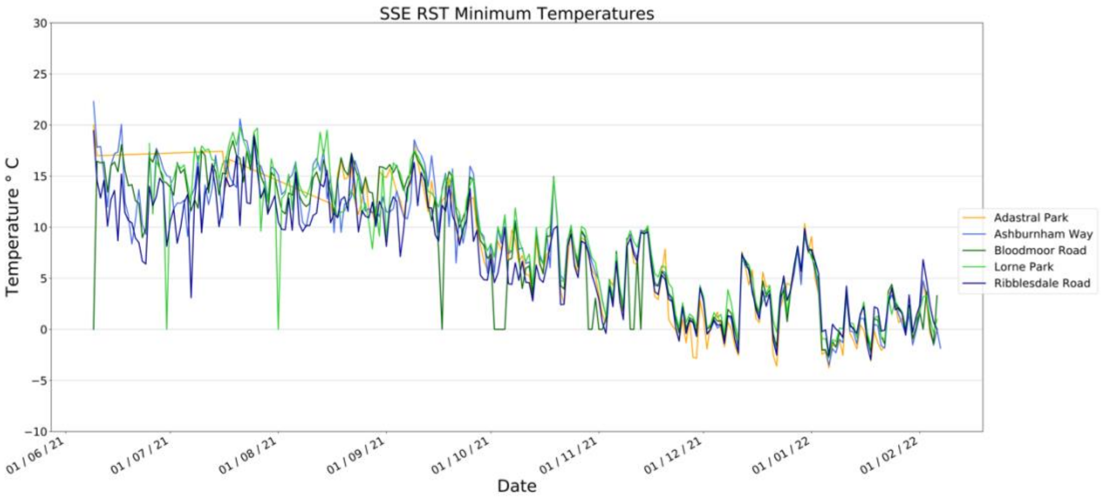


*Figure 32: SSE RST sensors, minimum daily temperature*

### 4.4.4 Inspection of installed units

Installed units were visited for a visual inspection. As the units were installed high on lighting columns, close inspection was not possible. Photography was used to reveal visually installation arrangements and resilience of the devices (Figure 33).

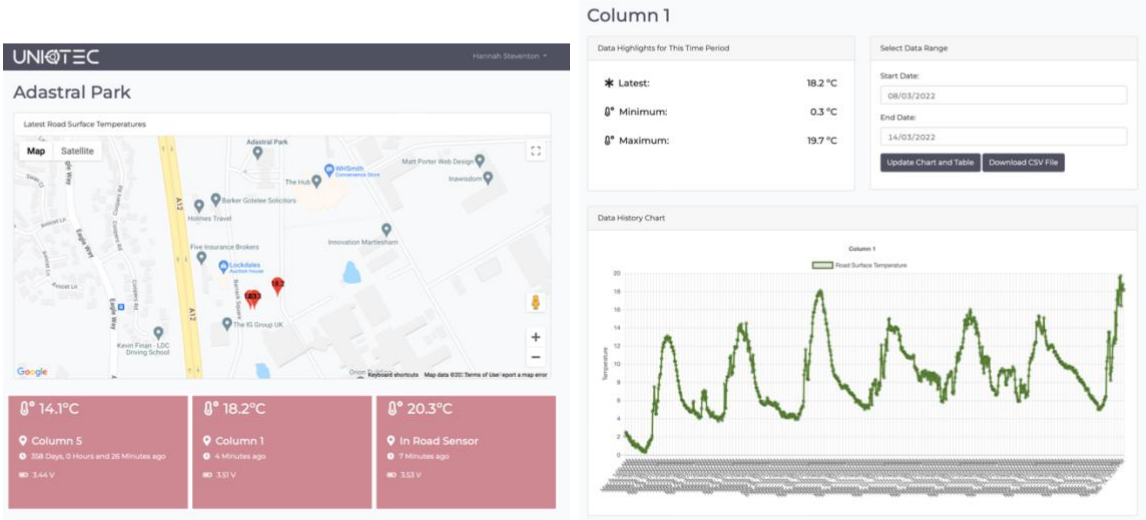
*Figure 33: Libelium RST and weather sensor supplied by SSE (photos: H Steventon)*

## 4.5 Uniotec sensor data

### 4.5.1 Installation and data access

Three road surface temperature sensors supplied by Uniotec (described in Sections 3.2 and 3.3) were installed at Adastral Park on street light columns.

Data from these sensors was available on the Smarter Suffolk BT Data Exchange, but for the purposes of this analysis was acquired as csv files downloaded from the supplier dashboard. Selected dashboard screenshots are included in Figure 34.



Adastral Park

Latest Road Surface Temperatures

14.1°C
Column 5
358 Days, 0 Hours and 26 Minutes ago
3.44 V

18.2°C
Column 1
4 Minutes ago
3.51 V

20.3°C
In Road Sensor
7 Minutes ago
3.53 V

Column 1

Data Highlights for This Time Period

Latest: 18.2 °C
Minimum: 0.3 °C
Maximum: 19.7 °C

Select Data Range

Start Date: 08/03/2022
End Date: 14/03/2022

Data History Chart

*Figure 34: Uniotec screenshots showing display of RST information*

### 4.5.2 Reliability

Connection was via the LoRaWAN gateway provided by BT Applied Research.

Measurements were taken at 20 minute intervals, and data has been analysed from 6 January 2020 to 7 February 2022.

Reliability analysis indicates that for most sensors there are gaps in data (over an hour) during the period of analysis. Analysis of length of gap (greater than 60 minutes) during the operational period has been undertaken, which indicates the following:

| Location | No of data points | No of gaps > 1 hr | Average gap in data | Longest gap in data |
|---|---|---|---|---|
| Column 1 | 113252 | 18 | 9 days 10:29 | 76 days 08:12 |
| Column 5 | 29901 | 74 | 2 days 06:27 | 56 days 04:59 |
| In Ground | 75864 | 34 | 5 days, 06:35 | 89 days 13:08 |

*Table 5: Gaps in data during the period analysed (approx. 25 months), Uniotec RST sensors, Adastral Park*

Uniotec were very active in supporting and developing their equipment, both proactive and responsive, with attendance on site. Early gaps in data led to hardware development, and resulted in longer battery lifespans. Gaps in data, where known, were due to initial connectivity challenges to a different gateway, power reduction and a casing failure on one device. Continuous product development resolved these issues.

### 4.5.3 Temperature data

Data from the three sensors was analysed for range of reported temperature.

Timeseries plots of this data for the complete period of analysis have been created (Figure 35). To illustrate the daily range, timeseries plots are also included for two separate months, June 2020 and February 2021 (Figure 36).

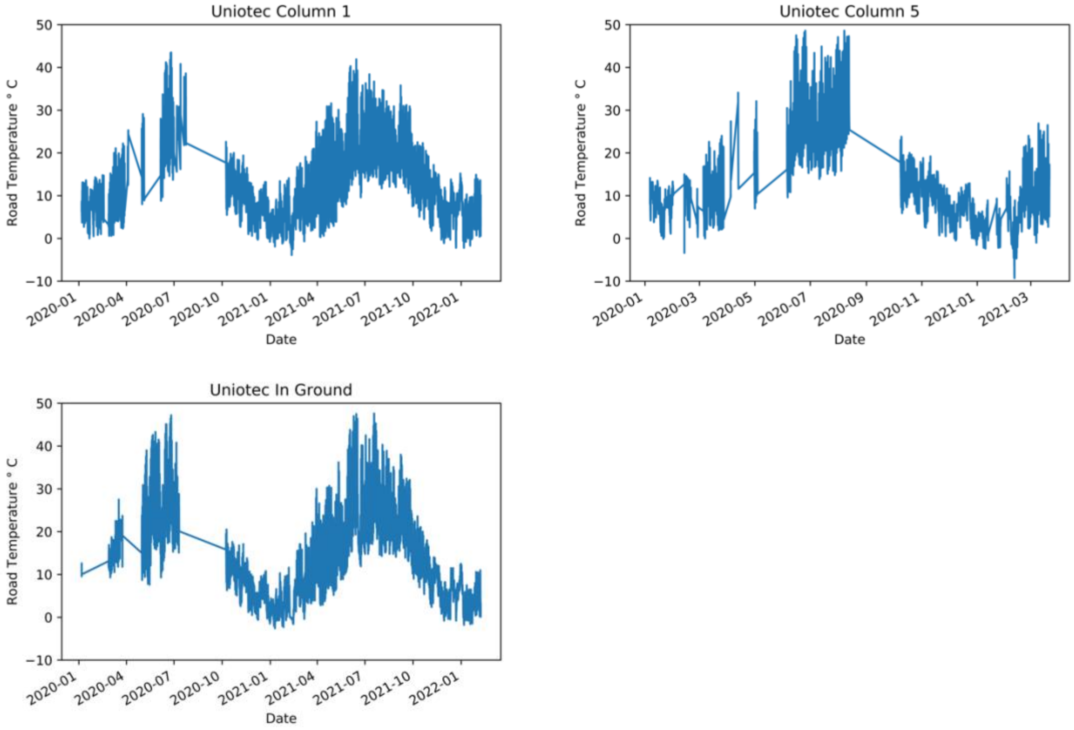


*Figure 35: Timeseries plots of temperature, Uniotec Road Surface Temperature Sensors, Adastral Park*

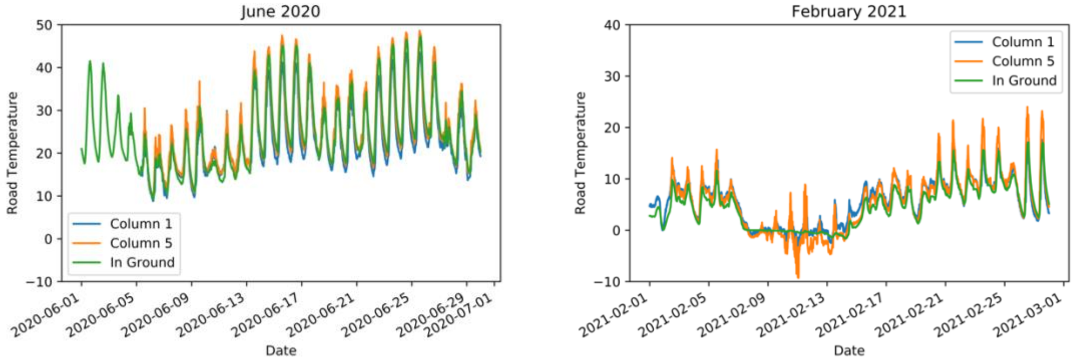


*Figure 36: Timeseries plots for selected months, Uniotec Road Surface Temperature Sensors, Adastral Park*

Initial observations from these plots indicate the daily fluctuations and seasonal range. As it is the minimum value for each day that is of most interest for gritting decision making, data for each sensor has been examined based on statistics for each day. For each day, the minimum temperature level, together with the interquartile range (25% - 75%) and 10% to 90% range, has been calculated for the data. The results of this analysis are shown in Figure 37 to Figure 39. These figures show the variation in daily temperature range through the operational period, which varies with weather and seasonally. They also shown the longer non-operational periods observed in all these sensors installed at Adastral Park. Comparisons of the daily minimum temperature measured by all these sensors is shown in Figure 40.

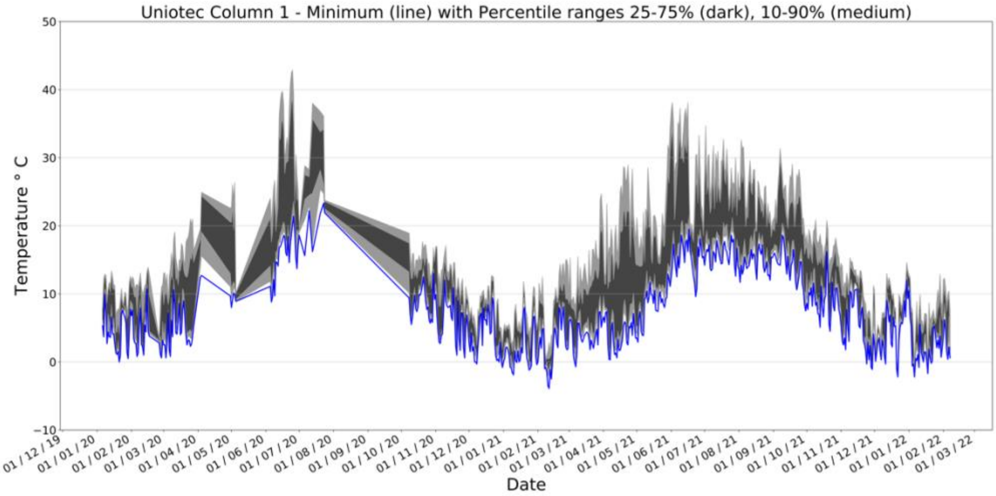


*Figure 37: Uniotec RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

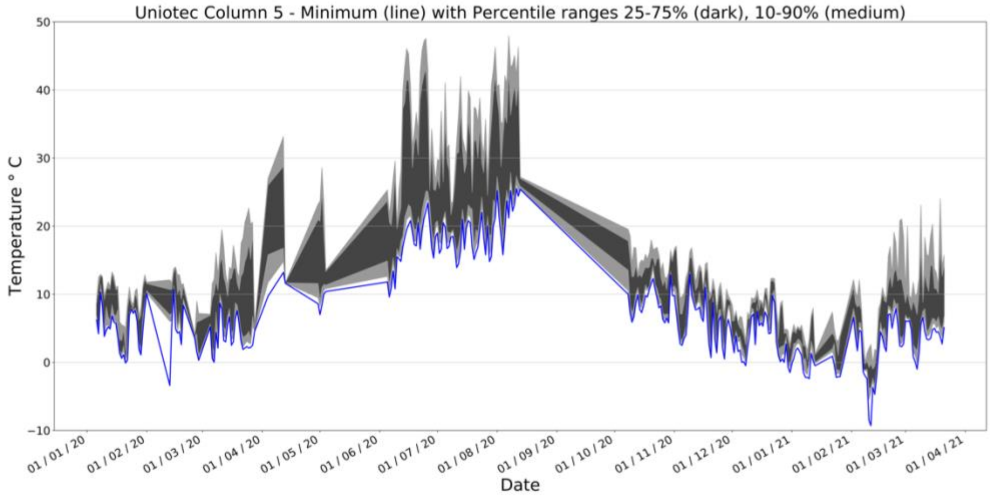


*Figure 38: Uniotec RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

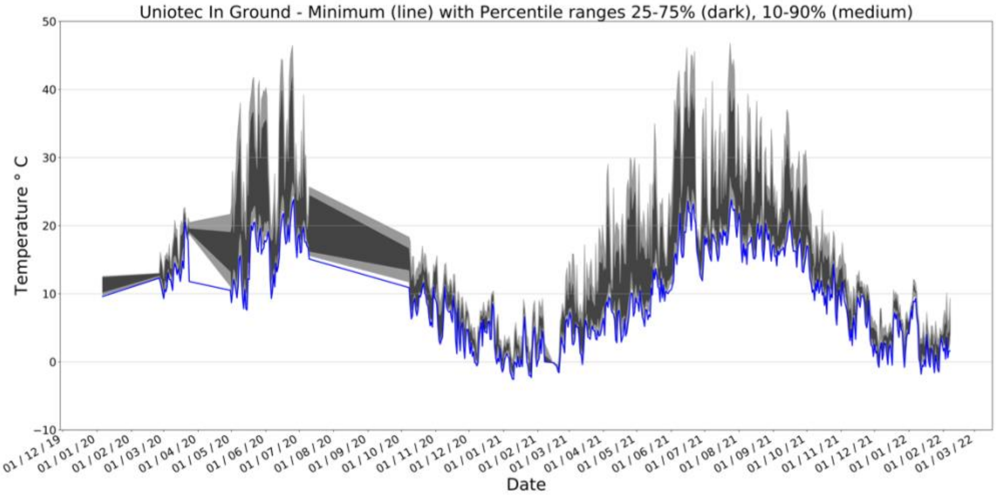


*Figure 39: Uniotec RST sensor, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

To compare the data from the three sensors, the daily minimums have been plotted together in Figure 40. This shows a varying correspondence between measurements reported by these sensors installed at identical or close locations at Adastral Park, with some differences in measured road surface temperature between these locations. During the second year of operation, temperatures measured by the in-ground sensor are higher than those measured by the remote sensor.

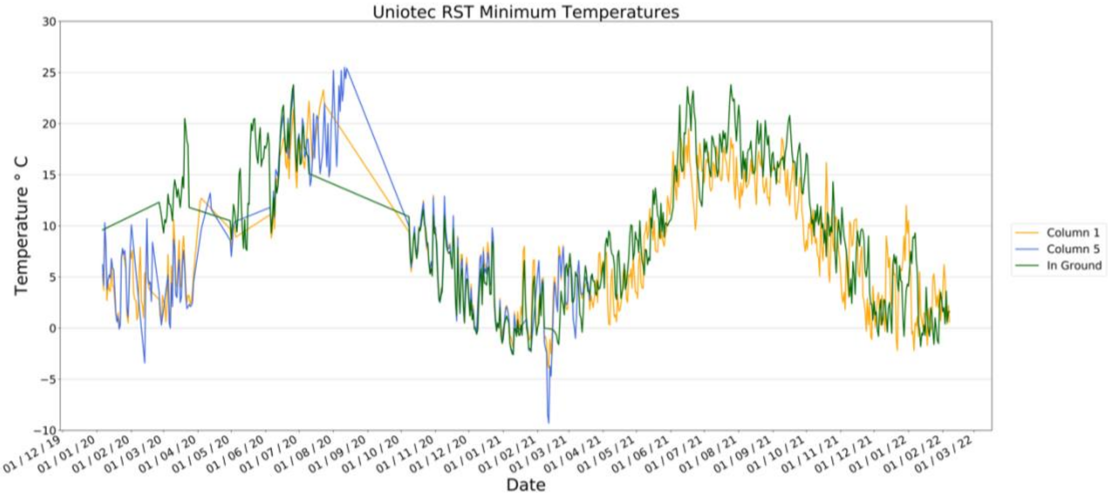


*Figure 40: Uniotec RST sensors, minimum daily temperature*

### 4.5.4 Inspection of installed units

Installed units were visited for a visual inspection. As the units were installed high on lighting columns, close inspection was not possible. Photography was used to reveal visually installation arrangements and resilience of the devices (Figure 41).

*Figure 41: UNIOTEC RST sensor (photos: H Steventon)*

## 4.6 Telensa sensor data

### 4.6.1 Installation and data access

Twenty three road surface temperature sensors supplied by Telensa (described in Section 3.7) were installed across Ipswich on street light columns.

Data from these sensors was available on the Smarter Suffolk BT Data Exchange, but for the purposes of this analysis was acquired as csv files provided by email from the supplier. A dashboard screenshot is included in Figure 42.

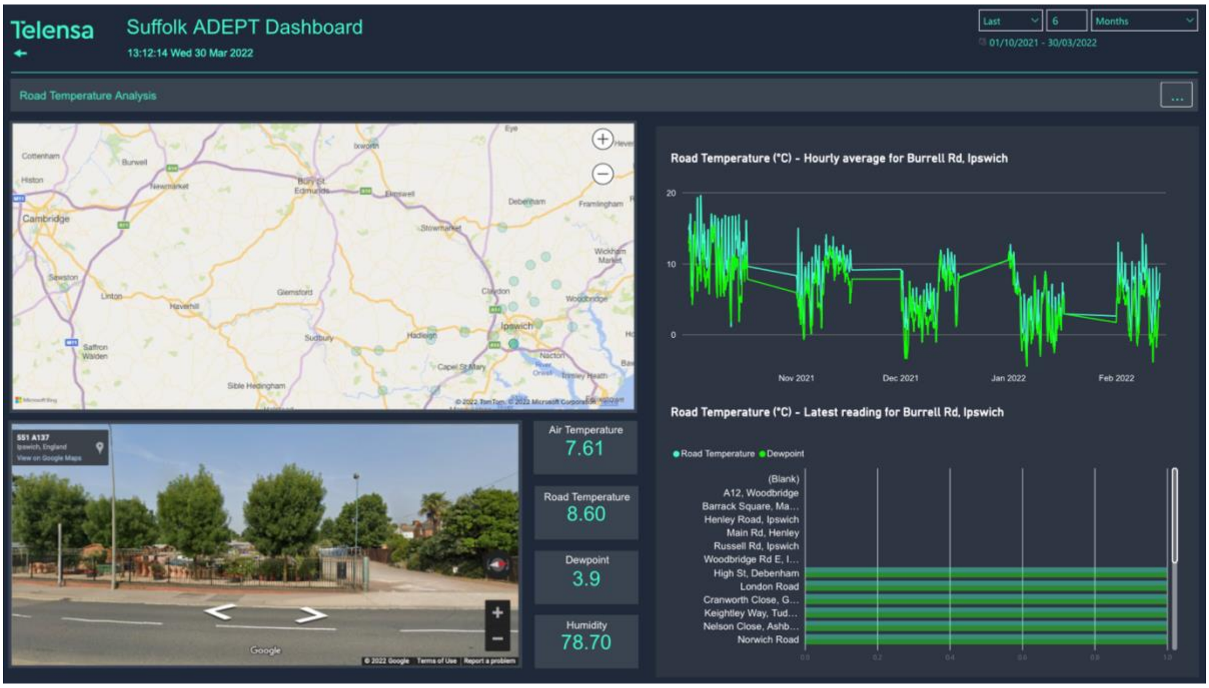

Telensa
Suffolk ADEPT Dashboard
13:12:14 Wed 30 Mar 2022
Last 6 Months
01/10/2021 - 30/03/2022
Road Temperature Analysis
Air Temperature 7.61
Road Temperature 8.60
Dewpoint 3.9
Humidity 78.70

Figure 42: Telensa UrbanIQ screenshots showing display of RST information

### 4.6.2 Reliability

Connection was via mobile data signals from column mounted communications hubs.

Measurements were taken at 1 minute intervals, and data has been analysed from October 2020 to October 2021

Reliability analysis indicates that for most sensors there are few gaps in data (over an hour) during the period of analysis. Analysis of length of gap (greater than 60 minutes) during the operational period has been undertaken, which indicates the following:

| Sensor | No of data points | No of gaps > 1 hr | Average gap in data | Longest gap in data |
|---|---|---|---|---|
| R242032 | 502724 | 10 | 2 days 19:33 | 13 days 18:38 |
| R352021 | 392284 | 11 | 11 days 03:11 | 63 days 09:55 |
| R352038 | 520550 | 6 | 5 days 13:07 | 19 days 06:39 |
| R242013 | 550835 | 2 | 6 days 01:21 | 11 days 18:21 |
| R507036 | 245787 | 4 | 34 days 16:11 | 65 days 12:19 |
| R284017 | 500894 | 8 | 5 days 18:50 | 19 days 01:53 |
| R242034 | 548732 | 4 | 3 days 09:05 | 11 days 17:37 |
| R284033 | 566731 | 3 | 0 days 15:40 | 1 days 11:32 |
| S063009 | 567536 | 1 | 0 days 08:21 | 0 days 08:21 |
| R284031 | 531798 | 6 | 4 days 05:25 | 16 days 16:20 |
| R352023 | 351143 | 7 | 17 days 07:34 | 36 days 08:10 |
| R246001 | 155113 | 6 | 23 days 17:57 | 70 days 17:34 |
| S063008 | 424754 | 1 | 08:21 | 08:21 |
| R507019 | 310888 | 4 | 18 days 13:23 | 44 days 23:57 |
| S063005 | 281527 | 8 | 8 days 23:11 | 46 days 15:58 |
| R352048 | 275840 | 4 | 22 days 04:41 | 72 days 15:52 |
| S063010 | 193121 | 4 | 31 days 18:38 | 84 days 18:02 |
| R242009 | 29399 | 3 | 14 days 10:42 | 41 days 10:04 |
| R222035 | 32416 | 1 | 08:20 | 08:20 |
| R274014 | 82986 | 1 | 08:21 | 08:21 |
| S063006 | 292470 | 5 | 11 days 14:33 | 34 days 17:25 |
| R507020 | 318562 | 4 | 9 days 22:46 | 21 days 21:47 |

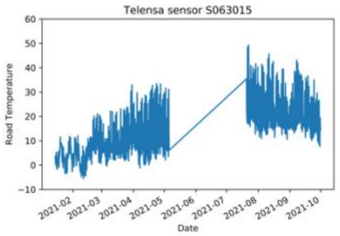
*Table 6: Gaps in data during the period analysed (13 months), Telensa RST sensors, Ipswich*

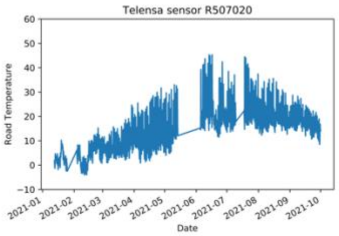
These indicate that there were not multiple short data gaps, as seen in some other sensors relating to intermittent communication coverage. However, when sensors did stop operating, a longer gap ensued and often required manual intervention to restart equipment.

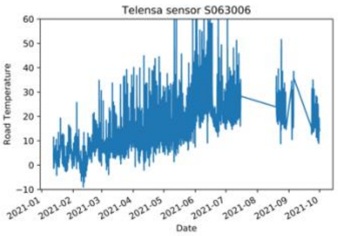
### 4.6.3 Temperature data

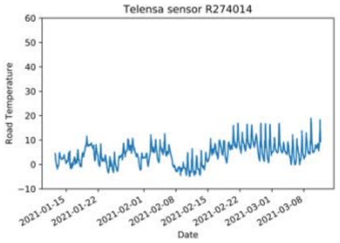
Data from the twenty three sensors was analysed for range of reported temperature.

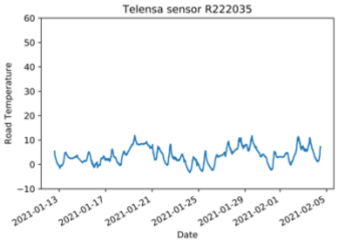
Timeseries plots of this data for the complete period of analysis have been created (Figure 35). For those sensors indicating a more limited range of values, this corresponds to a limited period of operation and therefore limited seasonal variation. To illustrate the daily range, timeseries plots are also included for two separate months, February 2021 and August 2021 (Figure 36).

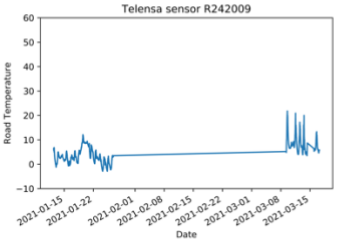

Telensa sensor S063015
Road Temperature
60
50
40
30
20
10
0
−10
2021-02
2021-03
2021-04
2021-05
2021-06
2021-07
2021-08
2021-09
2021-10
Date

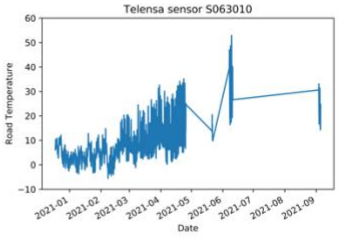

Telensa sensor R507020
Road Temperature
60
50
40
30
20
10
0
−10
2021-01
2021-02
2021-03
2021-04
2021-05
2021-06
2021-07
2021-08
2021-09
2021-10
Date

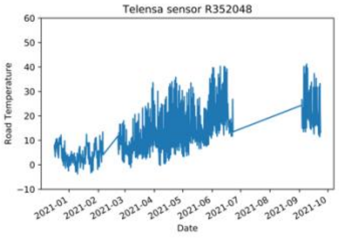

Telensa sensor S063006
Road Temperature
60
50
40
30
20
10
0
−10
2021-01
2021-02
2021-03
2021-04
2021-05
2021-06
2021-07
2021-08
2021-09
2021-10
Date

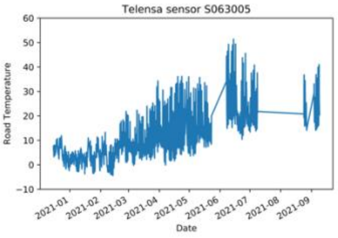

Telensa sensor R274014
Road Temperature
60
50
40
30
20
10
0
−10
2021-01-15
2021-01-22
2021-02-01
2021-02-08
2021-02-15
2021-02-22
2021-03-01
2021-03-08
Date

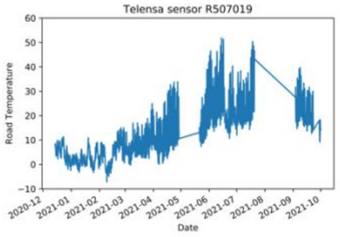

Telensa sensor R222035
Road Temperature
60
50
40
30
20
10
0
−10
2021-01-13
2021-01-17
2021-01-21
2021-01-25
2021-01-29
2021-02-01
2021-02-05
Date

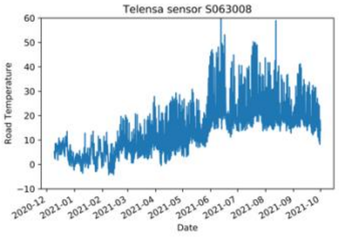

Telensa sensor R242009
Road Temperature
60
50
40
30
20
10
0
−10
2021-01-15
2021-01-22
2021-02-01
2021-02-08
2021-02-15
2021-02-22
2021-03-01
2021-03-08
2021-03-15
Date

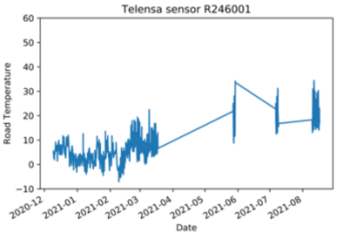

Telensa sensor S063010
Road Temperature
60
50
40
30
20
10
0
−10
2021-01
2021-02
2021-03
2021-04
2021-05
2021-06
2021-07
2021-08
2021-09
Date


Telensa sensor R352048
Road Temperature
60
50
40
30
20
10
0
−10
2021-01
2021-02
2021-03
2021-04
2021-05
2021-06
2021-07
2021-08
2021-09
2021-10
Date


Telensa sensor S063005
Road Temperature
60
50
40
30
20
10
0
−10
2021-01
2021-02
2021-03
2021-04
2021-05
2021-06
2021-07
2021-08
2021-09
Date


Telensa sensor R507019
Road Temperature
60
50
40
30
20
10
0
−10
2020-12
2021-01
2021-02
2021-03
2021-04
2021-05
2021-06
2021-07
2021-08
2021-09
2021-10
Date


Telensa sensor S063008
Road Temperature
60
50
40
30
20
10
0
−10
2020-12
2021-01
2021-02
2021-03
2021-04
2021-05
2021-06
2021-07
2021-08
2021-09
2021-10
Date


Telensa sensor R246001
Road Temperature
60
50
40
30
20
10
0
−10
2020-12
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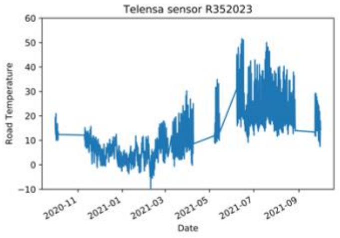
Date


Telensa sensor R352023
Road Temperature
60
50
40
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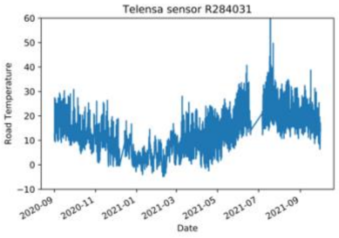
Telensa sensor R284031
Road Temperature
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50
40
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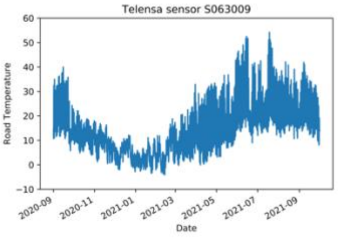
Telensa sensor S063009
Road Temperature
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50
40
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2020-09
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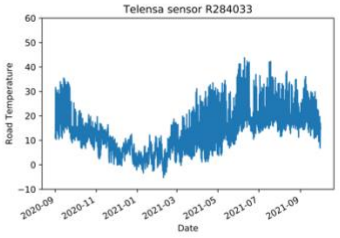
Telensa sensor R284033
Road Temperature
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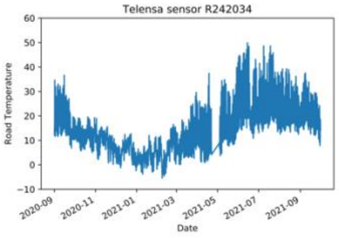
Date


Telensa sensor R242034
Road Temperature
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40
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2020-09
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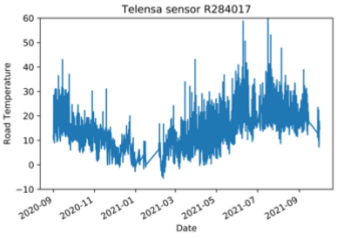
Date


Telensa sensor R284017
Road Temperature
60
50
40
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20
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2020-09
2020-11
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2021-07
2021-09
Date

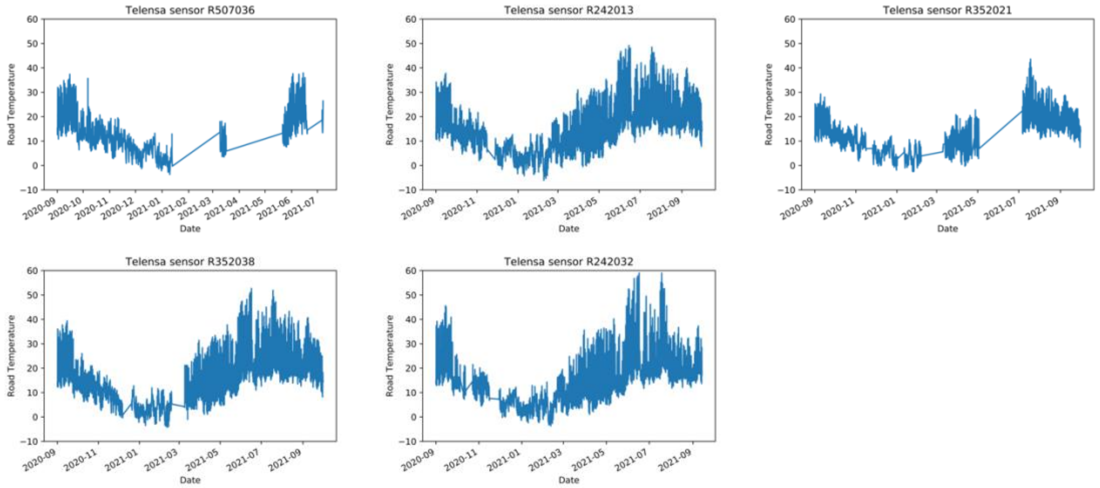


*Figure 43: Timeseries plots of temperature, Telensa Road Surface Temperature Sensors, Ipswich*

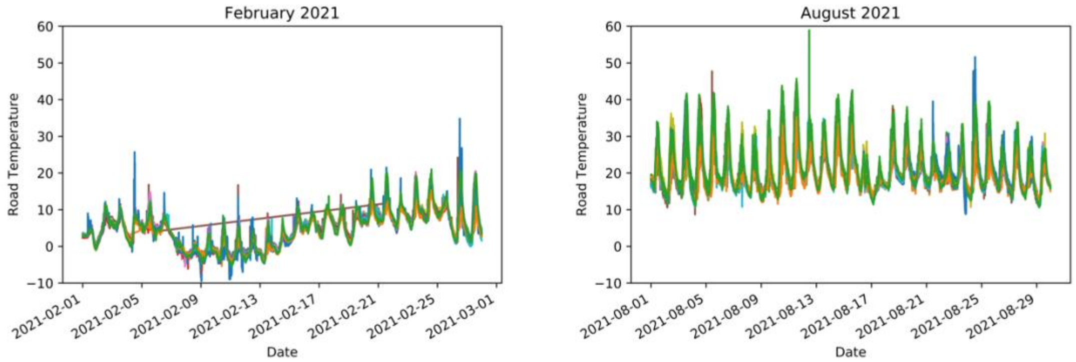
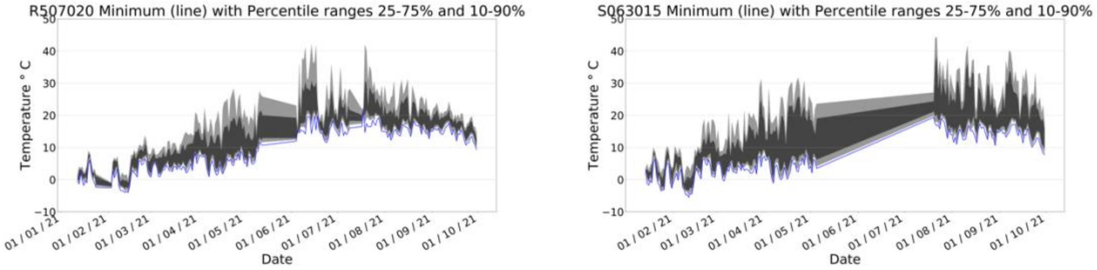
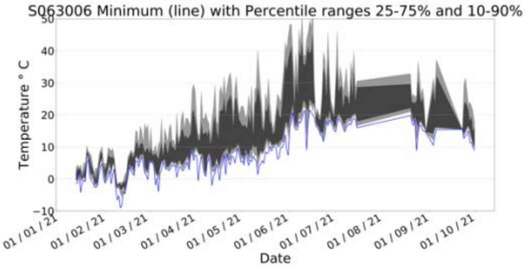
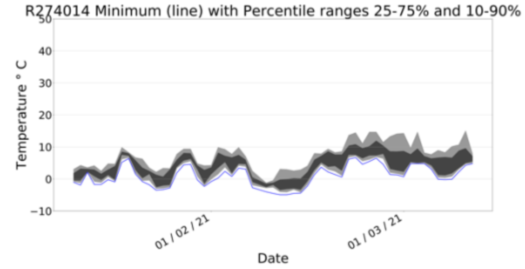


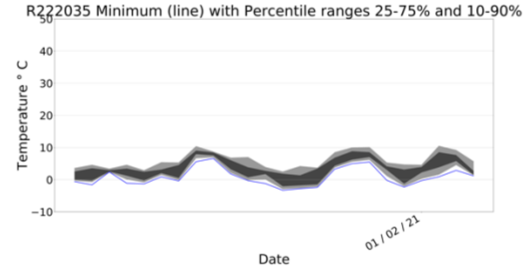
*Figure 44: Timeseries plots for selected months, Telensa Road Surface Temperature Sensors, Ipswich*

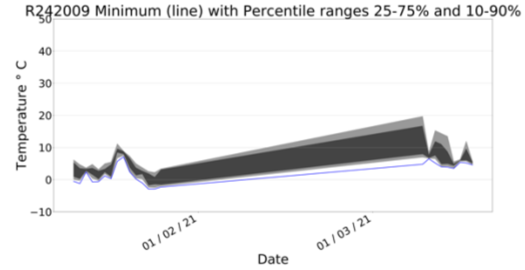
Initial observations from these plots indicate the daily fluctuations and seasonal range. As it is the minimum value for each day that is of most interest for gritting decision making, data for each sensor has been examined based on statistics for each day. For each day, the minimum temperature level, together with the interquartile range (25% - 75%) and 10% to 90% range, has been calculated for the data. The results of this analysis are shown in Figure 45. Due to the number of individual sensors, these timeseries plots have been presented in a smaller size. These figures show the variation in daily temperature range through the operational period, which varies with weather and seasonally. They also shown the longer non-operational periods observed in many of these sensors. Comparisons of the daily minimum temperature measured by all these sensors is shown in Figure 46. For sensors with much shorter time periods of operation, data appears less varied.

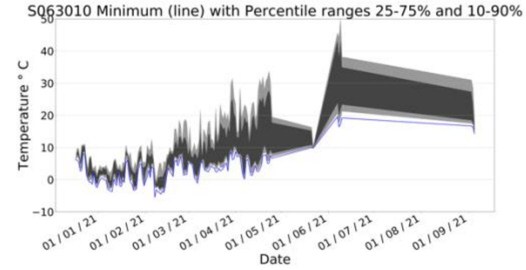


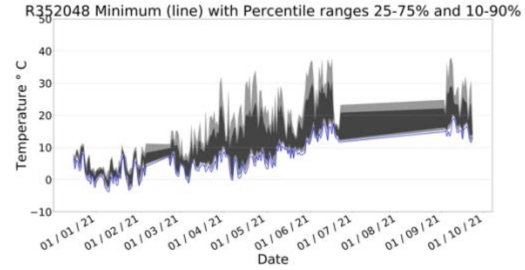

S063006 Minimum (line) with Percentile ranges 25-75% and 10-90%

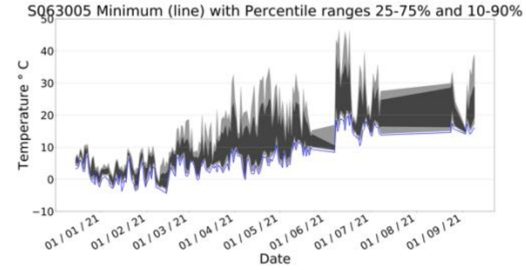

R274014 Minimum (line) with Percentile ranges 25-75% and 10-90%

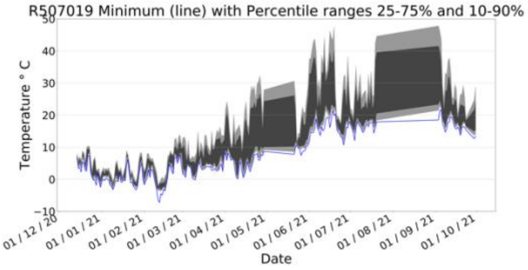

R222035 Minimum (line) with Percentile ranges 25-75% and 10-90%

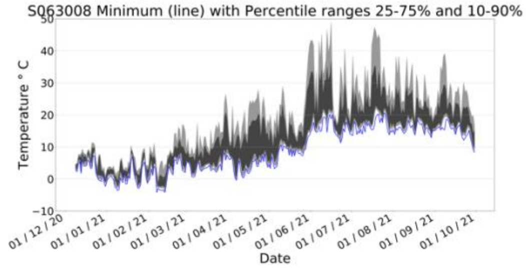

R242009 Minimum (line) with Percentile ranges 25-75% and 10-90%

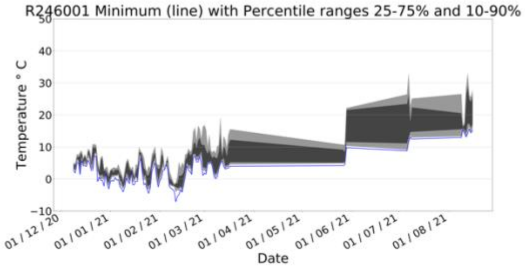

S063010 Minimum (line) with Percentile ranges 25-75% and 10-90%

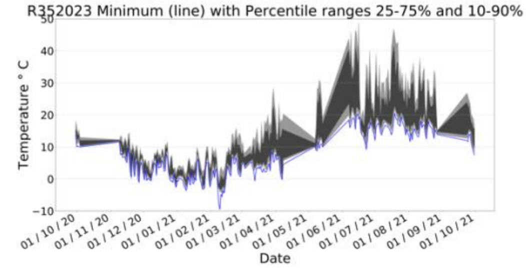

R352048 Minimum (line) with Percentile ranges 25-75% and 10-90%

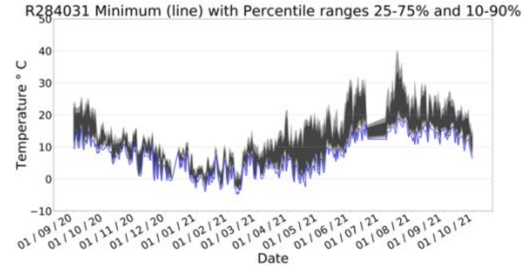

S063005 Minimum (line) with Percentile ranges 25-75% and 10-90%


R507019 Minimum (line) with Percentile ranges 25-75% and 10-90%


S063008 Minimum (line) with Percentile ranges 25-75% and 10-90%


R246001 Minimum (line) with Percentile ranges 25-75% and 10-90%


R352023 Minimum (line) with Percentile ranges 25-75% and 10-90%


R284031 Minimum (line) with Percentile ranges 25-75% and 10-90%

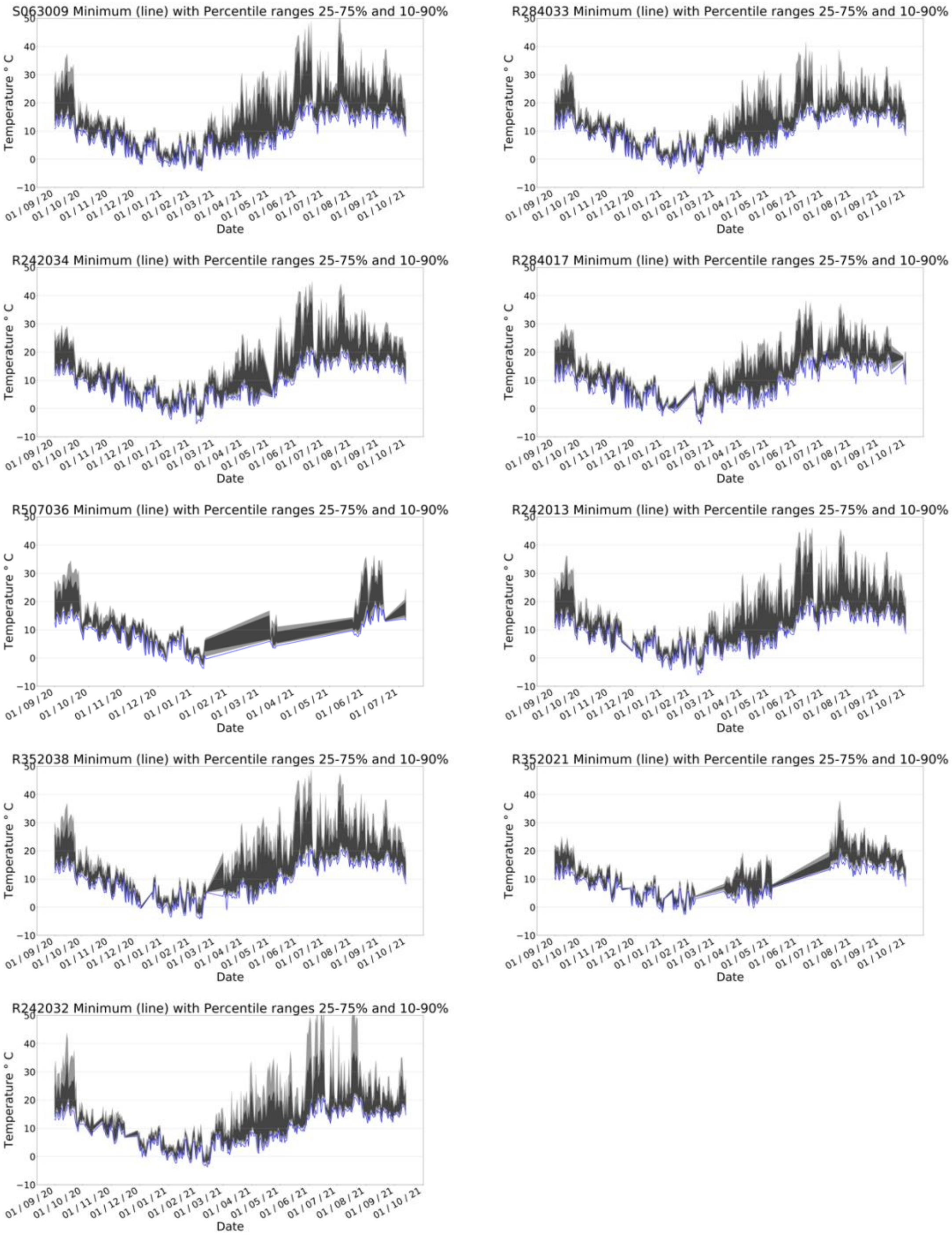


*Figure 45: Telensa RST sensors, minimum daily temperature*
*Minimum (line) with Percentile ranges 25-75% (dark), 10-90% (medium)*

To compare the data from the sensors, the daily minimums have been plotted together in Figure 46. This indicates a significant range in minimum temperature on some nights during the period of analysis. This shows a varying correspondence between measurements reported by these sensors installed at locations around Ipswich, with differences in measured road surface temperature between these locations being identified. The plot also indicates the challenges of periods of missing data.

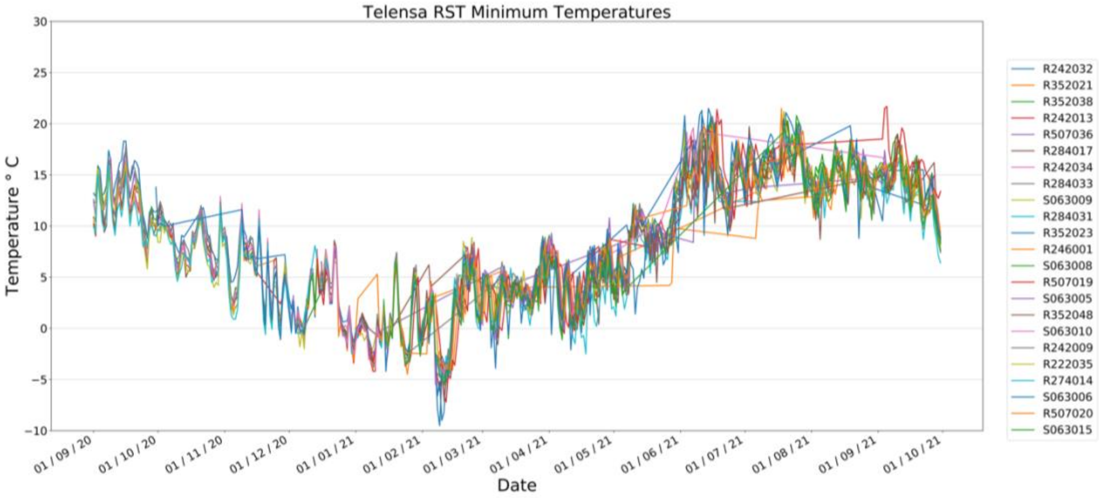


*Figure 46: Telensa RST sensors, minimum daily temperature*

### 4.6.4 Inspection of installed units

Installed units were visited for a visual inspection. As the units were installed high on lighting columns, close inspection was not possible. Photography was used to reveal visually installation arrangements and resilience of the devices (Figure 47).

*Figure 47: Vaisala RST sensor supplied by Telensa, campus location (photos: H Steventon)*

## 4.7 Adastral Park Comparisons

Installation of road temperature sensors from five suppliers very close to each other on two lighting columns at Adastral Park has enabled comparison of values measured by these sensors.

These sensors were:

- Aeroqual AQY1 sensors BC-1051 and BC-1052 installed by Telensa
- Libelium sensor ‘Adastral Park’ installed by SSE
- Three sensors from Uniotec, Column 1, Column 5 and in-ground.

Comparing dates for which data is available indicates that the period of concurrent operation is between January 2020 and December 2021, with different sensors operating at different times during this two year period. The complete data set across this period is shown in Figure 48. Initial observations from these plots indicate the daily fluctuations and seasonal range.

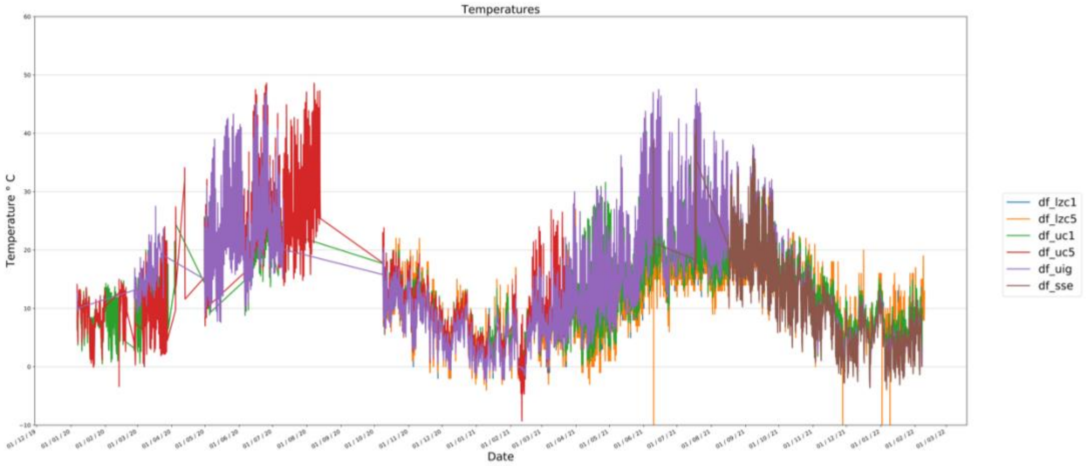


*Figure 48: Measured road surface temperature, Adastral Park, January 2020 to January 2022*

As it is the minimum value for each day that is of most interest for gritting decision making, data for each sensor has been examined based on statistics for each day. For each day, the minimum temperature level, together with the interquartile range (25% - 75%) and 10% to 90% range, has been calculated for the data. This is shown in Figure 49. Visual inspection of timeseries for this period reveals a range of data covering around 2°C at times.

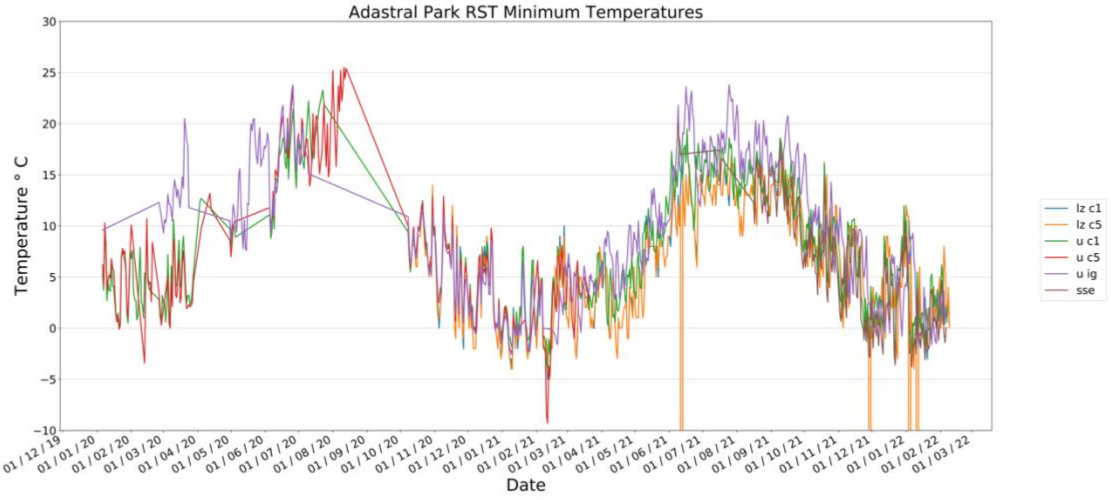
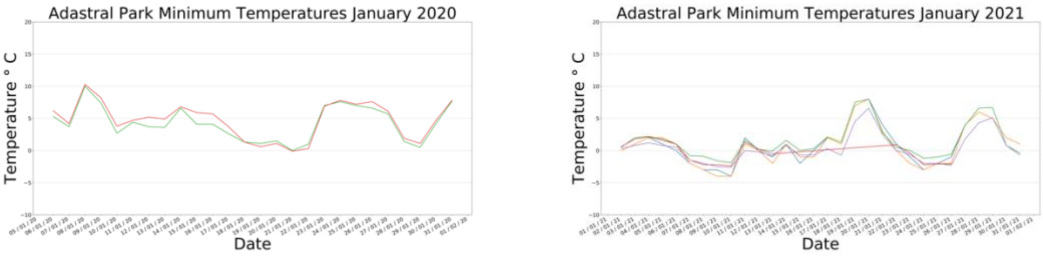
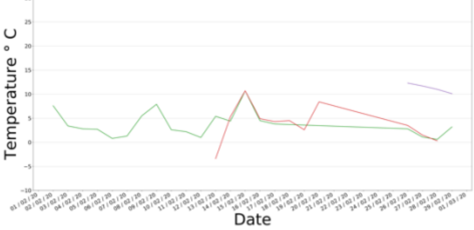
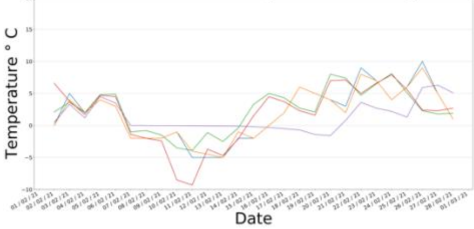


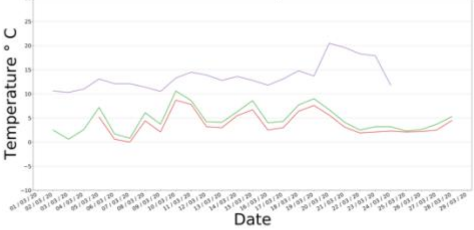
*Figure 49: Measured road surface temperature, Adastral Park, January 2020 to January 2022*

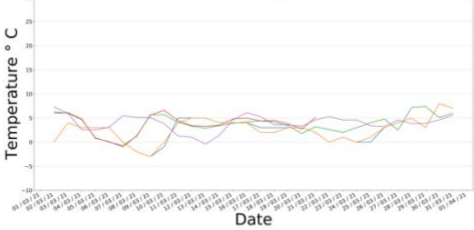
For visibility, this has been split into monthly data, which are shown below adjacent to the same month for the following year (Figure 50).

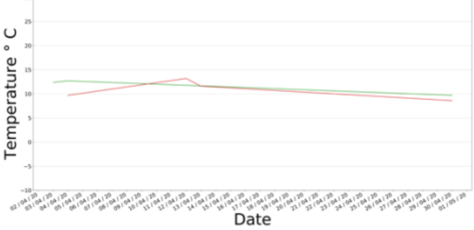



Adastral Park Minimum Temperatures February 2020

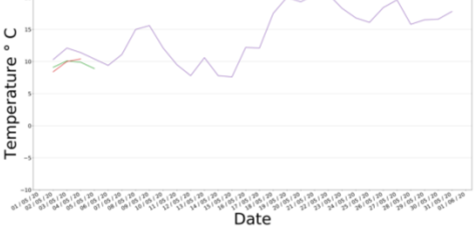

Adastral Park Minimum Temperatures February 2021


Adastral Park Minimum Temperatures March 2020

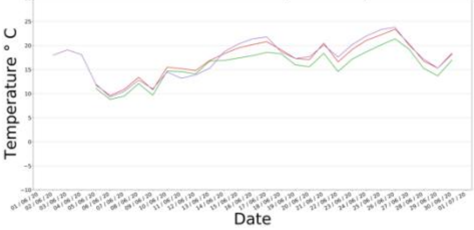

Adastral Park Minimum Temperatures March 2021


Adastral Park Minimum Temperatures April 2020

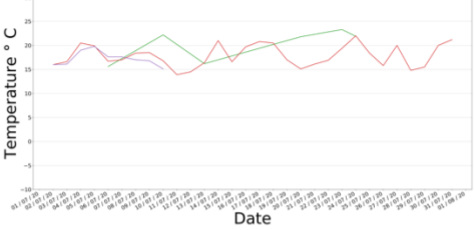

Adastral Park Minimum Temperatures April 2021

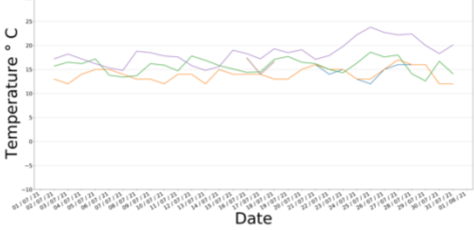

Adastral Park Minimum Temperatures May 2020

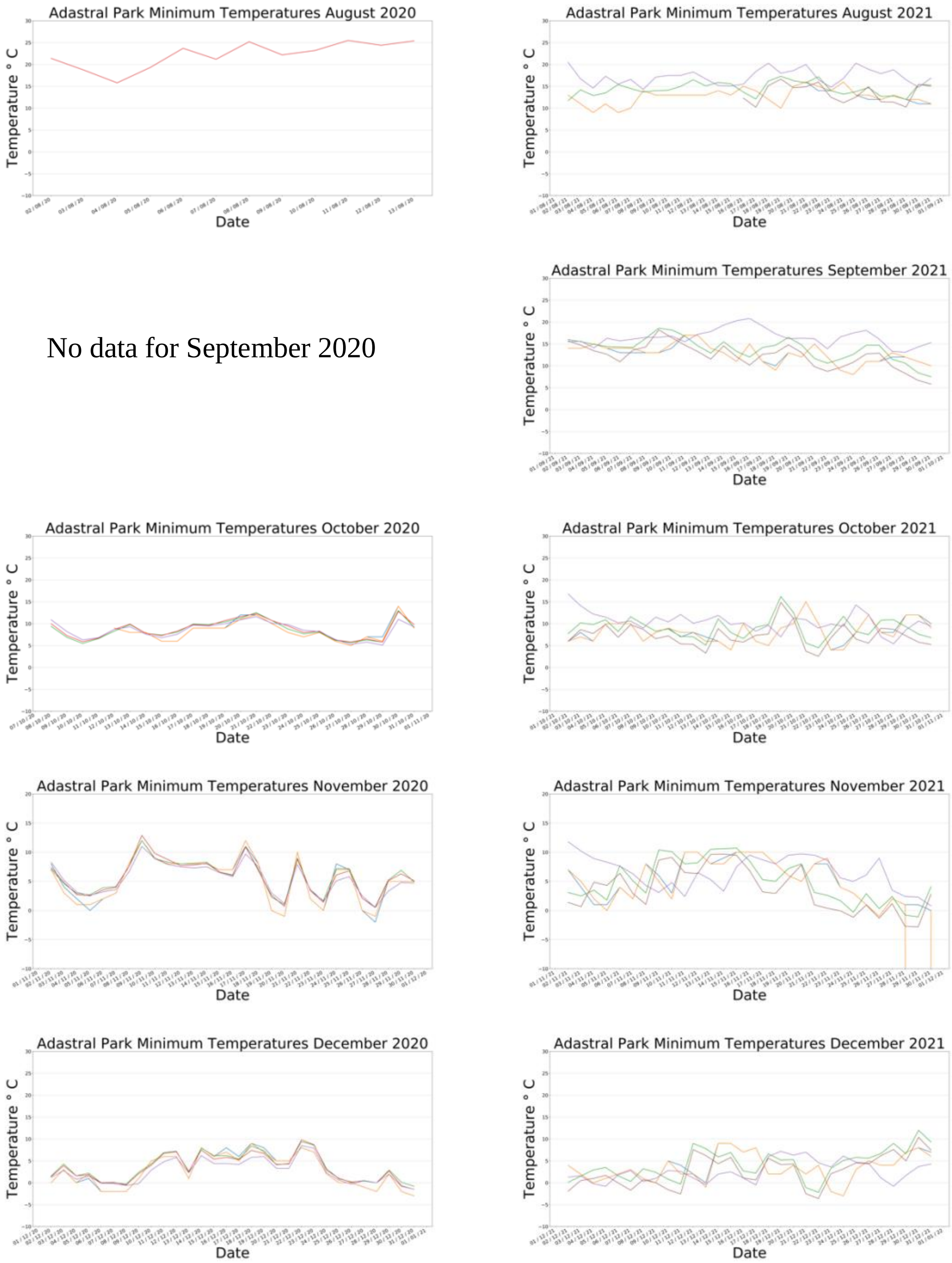

Adastral Park Minimum Temperatures May 2021


Adastral Park Minimum Temperatures June 2020


Adastral Park Minimum Temperatures June 2021


Adastral Park Minimum Temperatures July 2020


Adastral Park Minimum Temperatures July 2021



No data for September 2020

*Figure 50: Monthly measured road surface temperature, Adastral Park, January 2020 to January 2022*

This illustrates that calibration, sensitivity and date accuracy was strong at the start of the period, but has become poorer during the period of operation. This is most easily observed by comparing the plots for December 2020 and December 2021.

# 5 Financial Assessment / Business Case Inputs

## 5.1 Proactive and Reactive service provision

Service provision in Europe and the UK is proactive (precautionary) (National Winter Service Research Group, 2020c), based on weather forecasts enabling preventative winter gritting decision making. This process is dependent on the data accessed by an external weather forecasting company and granularity of the data provided by that forecasting company to the local authority decision makers. This contrasts with a reactive approach more commonly used in North America, where decisions are made based on real-time measurements, and are therefore less preventative.

The hypothesis is that in-fill sensors such as the ones in this trial are able to enable better decision making, which may be either more granular gritting, or more accurate decision making around the go / no-go condition boundary.

In order to apply this decision making in a pro-active, forecast-based decision process, the local authority needs an agreed process to include the in-fill sensor data into the decision-making protocols.

During the Smarter Suffolk project, DTN, SCC’s weather forecast provider, were able to access weather feeds from one of the sensor providers, and display these on a trial-specific dashboard, as a proof-of-concept. These were not integrated into the forecast or decision process. It is not yet apparent to what extent additional in-fill road surface temperature sensors will impact on weather forecasts provided for Suffolk. Additional work with the weather forecast provided may be possible to explore this possibility. Further exploration of the role of weather forecasting companies and potential for increased granularity is presented in (National Winter Service Research Group, 2020b).

Other local authorities known to be using road surface temperature in-fill sensors data have used the data for the re-definition of winter domains, and route optimisation (Kent County Council, 2021). They will also explore the use of route-based forecasting with their weather-forecaster (DTN Meteogroup, same as SCC). According to their winter service plan, Kent County Council are not using in-fill sensors within regular winter decision making. SCC has recently created winter domains; the exploration of route-based forecasting with the weather service provider is recommended.

## 5.2 Indicative costs of sensor provision

Due to the variety of sources and funding mechanisms encountered during this trial, a range of indicative costs for in-fill road surface temperature monitoring are presented here. All cost indication is exclusive of installation costs. For remote sensors (not installed into the ground, see Section 2.5.3) installation costs are comparable for each unit.

- Two of the suppliers provided sensors priced at £250 to £500 per unit. These measured road surface temperature only, or road surface temperature and air temperature, but not other parameters. They required an additional communications network to be provided (LoRaWAN in this case) at additional expense.
- One supplier provided a weather station solution, with multiple parameters, priced around £2,500 per unit. This used the supplier lighting communications network.
- Two of the suppliers provided sensors priced at around £5000 per unit. These measured road surface temperature only, or road surface temperature and air

temperature, but not other parameters. They used supplier lighting communications network or commercial mobile data communications.

More expensive solutions did not provide more usable data. However, costs and management of network solutions and data access must be considered in selecting a solution. If additional data were to be accessed by the weather forecasting supplier, their access to the data via an API, and the provision of usable parameters, is essential.

### 5.3 Financial comparison

Due to the process of incorporating in-fill sensor data into the winter decision-making protocol, direct comparison of potential savings by using additional in-fill sensors could not be made. Should SCC wish to explore further granularity of their winter gritting process, exploration of route-based forecasting with their weather forecast provider would be appropriate.

### 5.4 Environmental and Social Analysis

As described in Section 2.3.1, gritting is an essential part of winter highways management. De-icing in locations of need has significant social benefits, with increased mobility and reduced injury.

Conversely, the provision of Internet of Things and “Smart City” sensors in general also has some environmental disbenefits (Alsamhi *et al.*, 2019; Yang *et al.*, 2021) including: the manufacture, delivery and installation of the sensors; the energy required for their ongoing operation; energy for their data communication, management, storage and access; and end-of-life disposal.

As discussed in detail in Section 2.4, winter gritting, salt and de-icing agents have an environmental impact. This includes impact to surface water, groundwater, soils and vegetation.

Use of road surface temperature sensors with increased granularity could minimise the environmental impact of grit spreading (including provision of salt, application of salt to the environment, and use of vehicles to do so) whilst maintaining social and health benefits. This would require a pathway to include this additional information in the winter gritting decision making process, as discussed in Section **Error! Reference source not found.**.

## 6 Conclusions and Recommendations

### 6.1 Conclusions

This report concludes that the provision of lower-cost, more granular road surface temperature sensors has the potential to inform Suffolk County Council of finer scale variation in winter gritting requirements.

This report also concludes that existing winter gritting decision making protocols do not support the input of real-time data by the county council, as gritting decisions are preventative and proactive, made on the basis of forecast conditions provided by a specialist supplier.

## 6.2 Recommendations

It is recommended that SCC identifies how increased measurements can be incorporated into its winter management protocols on an ongoing basis:

- It is recommended that the weather forecaster is approached further to explore whether they are able to incorporate the measurements into their data inputs, and whether these impact their forecast output.
- Increased granularity of gritting could be achieved either as increased numbers of domains or, more feasibly, as route-based forecasting, which can be provided by the existing forecaster.
- SCC could explore whether other local authorities are incorporating real-time measurements into their decision protocol subsequent to or separate from the forecasting process.

Provision of lower cost “in-fill” road surface temperature sensors reporting in real time remains a developing field. Analysis of the reliability and operational consistency of the sensors has revealed that a high level of intervention is required to maintain operation. This is not sustainable for deployed instrumentation. Reliability of sensor operation should be expected of suppliers.

It is recommended that Suffolk County Council explore with other local authorities their position and approach on including information from infill sensors in gritting decisions, as the local authority’s policy on winter gritting decision making will be critical in implementing the output of infill sensors. Pricing across these various sensors is from £300 to £5000, and it is considered that the cheaper sensors have the potential to add useful and more granular information across the county, to increase further the targeting of Suffolk’s gritting decisions.

### 6.2.1 Parameters

This project has focused on measurement of the road surface temperature itself. Some sensors also measure additional parameters of use for weather forecasting and gritting decision making: some of these sensors also measure air temperature, and some relative humidity, with a variation in parameters between devices.

### 6.2.2 Data Quality and Management

Analysis of the data gathered from these sensors has required a very high level of data acquisition, management and manipulation. This should be managed by suppliers. This includes management of missing or null values. Data acquisition, management and manipulation has reduced the data analysis that could be undertaken within the project timescale.

Presentation and management of data from different suppliers differed, and in some cases caused problems. The following recommendations are made.

- Null or missing data points should be left empty or filled with values that can be clearly identified as inaccurate. The provision of values of ‘zero’ from one supplier presents problems with data usage. Further work in anomaly detection is planned using this data.
- It is essential that units for analysis are accurate and clearly provided. From some suppliers, data headings were missing or changed during the period of operation.

- Access to data to specified users is required including visualisation and running reports; for ease of access to users, and for ease of provision to this access, this should be configurable in the supplier dashboard or data access. API access is required for integration with weather forecasting services.
- Calibration and maintenance should be managed by the supplier.

### 6.2.3 Sensors and communications networks

Five different sensors have been trialled within this project, and wider options are available. Consideration of reliability and calibration of the data, in the context of the use of the data, should be applied to selection of products. Ongoing development of the specific sensors trialled, and other sensors in the comparable market, has meant that it is not appropriate to recommend any specific device. However, price was not found to be an indication of value of data.

The sensors trialled operated using different data communications methods. Most road surface temperature sensors in this project used provided networks, either from Zigbee local area networks operated by and for street lighting, or long range LoRaWAN networks provided locally for this project by BT, but which could be provided by city or county services such as the Suffolk and Norfolk Innovation Network. Sensors across all networks had some gaps in continuity of data. Provision of suitable communications network is an essential part of device selection. It was found that devices using local area Zigbee networks needed to be located well within the mesh network area, close to street lights, and therefore this solution is not practical across the rural areas of Suffolk. LoRaWAN has the potential to offer long range connectivity, but this has not been successfully trialled within this project.

Whilst use of existing street lighting communications networks for return of data has appeared unreliable in this project, it remains an interesting solution to minimise operational costs. This report recommends that further development and field testing of street lighting communication networks by suppliers and testing by users is required prior to reliance for ongoing data capture.

### 6.2.4 Installation

Road surface temperature sensors can be remote, measuring infra-red radiation emitted by the road surface, or contact sensors installed in slots cut in the ground. Whilst some in-ground sensors were installed at the trial test-bed, the installation challenges and road maintenance requirements precluded their wider use. Remote temperature sensors are considered easier to install directly on a column, and less vulnerable to damage in road maintenance. Installation on existing street furniture such as street lighting is convenient and can provide power as required.

Some sensors were battery powered and some powered via the lighting column. Both power options proved useable.

### 6.2.5 Management and financial structure

Reliability of sensors was variable across the project. It is recommended that council service managers work closely with suppliers to require and achieve a higher level of reliability of data, and support in event of operational issues.

### 6.3 Final Summary

The research within the Smarter Suffolk Live Labs project suggests that it is possible to install road surface temperature sensors on lighting columns. The majority of the sensors trialled use power from the lighting column supply, with two suppliers providing battery powered sensors.

Wider use of road surface temperature sensors requires integration with weather forecast suppliers, or incorporation of real-time data into the winter gritting decision protocol. Work with the National Winter Service Research Group and / or the weather forecasting supplier is needed to incorporate the output of additional infill sensors into the decision making protocols within the local authority.

It is anticipated that increased granularity of decision-making, such as route-based forecasting, will reduce the economic and environmental impact of winter gritting.

## 7 Discussions

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## 8 References

Alsamhi, S. H. *et al.* (2019) ‘Greening internet of things for greener and smarter cities: a survey and future prospects’, *Telecommunication Systems*, 72(4), pp. 609–632. doi: 10.1007/s11235-019-00597-1.

Apogee Instruments (no date) *SI-411-SS: Research-Grade SDI-12 Digital Output Standard Field of View Infrared Radiometer Sensor*. Available at: https://www.apogeeinstruments.com/si-411-ss-research-grade-sdi-12-digital-output-standard-field-of-view-infrared-radiometer-sensor/.

Chapman, L. and Bell, S. J. (2018) ‘High-Resolution Monitoring of Weather Impacts on Infrastructure Networks Using the Internet of Things’, *Bulletin of the American Meteorological Society*. Boston MA, USA: American Meteorological Society, 99(6), pp. 1147–1154. doi: 10.1175/BAMS-D-17-0214.1.

Cooper, C. A., Mayer, P. M. and Faulkner, B. R. (2014) ‘Effects of road salts on groundwater and surface water dynamics of sodium and chloride in an urban restored stream’, *Biogeochemistry*. Dordrecht: Springer Nature B.V., 121(1), pp. 149–166. doi: http://dx.doi.org/10.1007/s10533-014-9968-z.

Environment Agency (1990) *Pollution Prevention Guidelines Highway Depots: PPG10*. Available at: https://www.netregs.org.uk/media/1454/ppg-10.pdf.

Hammond, D. S., Chapman, L. and Thornes, J. E. (2010) ‘Verification of route-based road weather forecasts’, *Theoretical and Applied Climatology*, 100(3), pp. 371–384. doi: 10.1007/s00704-009-0189-7.

Handa, H., Chapman, L. and Yao, X. (2006) ‘Robust route optimization for gritting/salting trucks: a CERCIA experience’, *IEEE Computational Intelligence Magazine*, 1(1), pp. 6–9. doi: 10.1109/MCI.2006.1597056.

Hickman, L. (2010) ‘Is gritting the roads bad for the environment?’, *The Guardian*. Available at: https://www.theguardian.com/environment/2010/jan/14/rock-salt-bad-for-environment.

Jackson, J. K. and Funk, D. H. (2019) ‘Temperature affects acute mayfly responses to

elevated salinity: Implications for toxicity of road de-icing salts’, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 374(1764). doi: 10.1098/rstb.2018.0081.
Jamshidi, A., Goodarzi, A. R. and Razmara, P. (2020) ‘Long-term impacts of road salt application on the groundwater contamination in urban environments’, *Environmental Science and Pollution Research*, 27(24), pp. 30162–30177. doi: 10.1007/s11356-020-09261-7.
Jonsson, P. and Riehm, M. (2012) ‘Infrared Thermometry in Winter Road Maintenance’, *Journal of Atmospheric and Oceanic Technology*, 29(6), pp. 846–856. doi: 10.1175/JTECH-D-11-00071.1.
Kent County Council (2021) *Kent County Council Winter Service Policy Highway Operations Policy for 2021/22 Winter Service Period*. Available at: https://www.kent.gov.uk/__data/assets/pdf_file/0005/18977/Kent-Winter-Service-Plan.pdf.
Libelium (no date a) *Libelium PLug & Sense*. Available at: https://www.libelium.com/iot-products/plug-sense/ (Accessed: 15 January 2021).
Libelium (no date b) *Sensors probes*. Available at: https://development.libelium.com/smart-agriculture-xtreme-sensor-guide/sensors-probes (Accessed: 4 April 2022).
Libelium (no date c) *Smart Cities Pro Sensor Guide*.
MeteoGroup (2019) *MeteoGroup RoadMaster factsheet brochure*. Available at: https://www.meteogroup.com/sites/default/files/meteogroup_roadmaster_brochure.pdf (Accessed: 21 October 2019).
National Winter Service Research Group (2019a) *De-Icer Types*. Available at: https://nwsrg.org/de-icer-types.
National Winter Service Research Group (2019b) *Treatment Methodologies & Technologies*. Available at: https://nwsrg.org/treatments-methods.
National Winter Service Research Group (2020a) *Salt Storage*. Available at: https://nwsrg.org/salt-storage.
National Winter Service Research Group (2020b) *Weather Forecasting and Road Weather Information Systems*. Available at: https://nwsrg.org/nwsrg-practical-guide-for-winter-service-weather-forecasting-rwis.
National Winter Service Research Group (2020c) *Winter Service Decision Making*. Available at: https://nwsrg.org/7-winter-service-decision-making.
National Winter Service Research Group (2021) *Winter Service on Footways and Cycleways*. Available at: https://nwsrg.org/11-treatments-for-footways-and-cycleways.
Ordóñez-Barona, C. *et al.* (2018) ‘De-icing salt contamination reduces urban tree performance in structural soil cells’, *Environmental Pollution*, 234, pp. 562–571. doi: 10.1016/j.envpol.2017.11.101.
Rivett, M. O. *et al.* (2016) ‘Highway deicing salt dynamic runoff to surface water and subsequent infiltration to groundwater during severe UK winters’, *Science of The Total Environment*, 565, pp. 324–338. doi: https://doi.org/10.1016/j.scitotenv.2016.04.095.
Steventon, H. (2021) *Communications Networks for A Smarter Suffolk*.
Suffolk Highways (2018) *Winter Service Plan 2018-2019*. Available at: https://www.suffolk.gov.uk/assets/Roads-and-transport/check-which-roads-are-gritted/Winter-Service-Plan-2018-2019.pdf (Accessed: 21 October 2019).
Suffolk Highways (2019) *Winter Service Plan 2019-2020*. Available at: https://www.suffolk.gov.uk/assets/Roads-and-transport/check-which-roads-are-gritted/2019-11-07-FINAL-WS-Plan-19-20-v2-for-web.pdf (Accessed: 26 June 2020).
Vaisala (2019a) *DST111 Remote Surface Temperature Sensor*. Available at: https://www.vaisala.com/en/products/instruments-sensors-and-other-measurement-devices/weather-stations-and-sensors/dst111 (Accessed: 21 October 2019).
Vaisala (2019b) *Remote Surface Temperature Sensor DST111 Datasheet*. Available at:

https://www.vaisala.com/sites/default/files/documents/DST111-Datasheet-B210471EN.pdf (Accessed: 21 October 2019).
Vignisdottir, H. R. *et al.* (2019) 'A review of environmental impacts of winter road maintenance', *Cold Regions Science and Technology*, 158, pp. 143–153. doi: https://doi.org/10.1016/j.coldregions.2018.10.013.
Yang, Z. *et al.* (2021) 'Green Internet of Things and Big Data Application in Smart Cities Development', *Complexity*, 2021. doi: 10.1155/2021/4922697.

## 9 Document History

| **Date** | **Version** | **Author** | **Notes** |
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