TRANSPORATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (University or Contractor):__Kansas DOT___________________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Project Number **TPF-5(351)**	**Transportation Pooled Fund Program - Report Period:** X Quarter 1 (January 1 – March 31) ☐ Quarter 2 (April 1 – June 30) ☐ Quarter 3 (July 1 – September 30) ☐ Quarter 4 (October 4 – December 31)

Project Title: Self De-Icing LED Signals

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Lead Agency Project ID: **RE-0721-01**	**Other Project ID (i.e., contract #):**	**Project Start Date:** August 15, 2016
Original Project End Date: **August 2019**	**Current Project End Date:** **June 2021**	**Number of Extensions:** 1

Project schedule status:

☐ On schedule X On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Total Percentage of Work Completed
$240,000 original, $360,000 with addendum	$264,066.24	82%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$10,763.36	$10,763.36	3%

Project Description:

This pooled fund project will develop and demonstrate new self de-icing LED signals for highway signalized intersections and railroad signaling applications to solve a well-known problem of the existing LED signal light whose lens is too cool to melt snow and de-ice in wintery conditions. The self de-icing LED signals will adopt one or both of two novel architectures (Figure 1), including (a) “Heated Lens Lighting Arrangement” that uses a single high-power LED and (b) “Heat Arrangement of LED Arrays in Low Profile” that deploys multiple LEDs. The heat generated by the LED(s) is harvested by the passive heat exchanger and stored to heat the lens for melting snow and de-icing in wintery conditions.

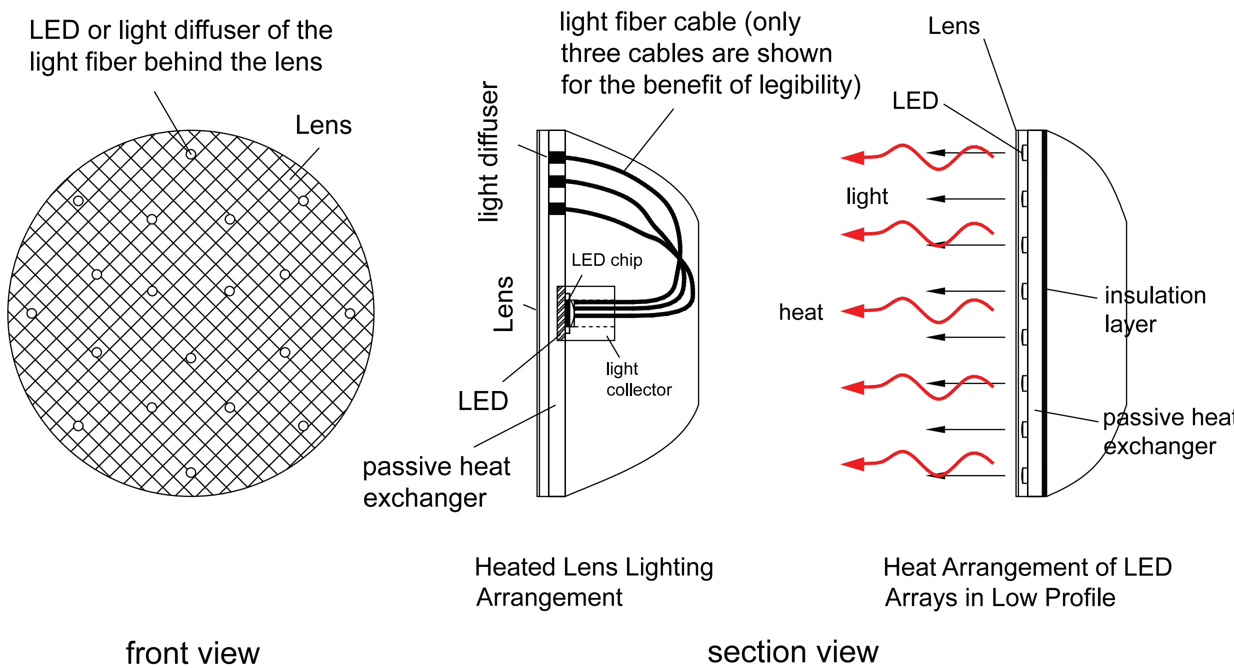


Figure 1 The concept of the self de-icing LED signal light, which adopts new architecture of “Heated Lens Lighting Arrangement” or “Heat Arrangement of LED Arrays in Low Profile”

Fully working prototypes of the self-de-icing LED signals have been developed and tested in the laboratory. They have been tested in closed-course settings on the roof of an engineering building followed by field tests on highway intersection or railroad wayside or at-grade crossing signal lights. Each participating agency is required to provide support of three years of funding ($20,000/year, totaling $60,000) and will be guaranteed a field test site in each state for testing the fully working prototypes catering to their specific needs of the new type of signals. The research team will work with each participating agency to identify the desired test site on highway intersections or rail track sections and the desired technical specifications for testing the prototypes.

The investigative approach for the proposed project is divided into three stages. Work in Stage 1 focuses on laboratory development and tests. Work in Stage 2 focuses on testing the three prototypes in a closed-course setting on the roof of the University of Kansas engineering complex and powered by the signal controller cabinet. Work in the third and final stage involves field testing of the developed prototypes on identified test sites. On-site demonstration of the prototype signals will also be held for project partners and state DOTs to initiate the implementation process. A final report will provide all relevant data and results along with plans for implementation of the self-de-icing LED signals in affected states.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

During the first quarter (Jan 1, 2020 – Mar 31, 2020) of the project period, we have the following accomplishments.

In the present quarter (Jan 1, 2020 – Mar 31, 2020), preparations are continuously undergoing for five more field tests in other states (California, Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland), in addition to the first field test already installed in Kansas. New fully functional prototypes of the signal lights for field tests were assembled and continuously tested in the laboratory in preparation for field tests. We have been developing a remedying method in the laboratory for flattening the defective plastic housing produced with concaved lens surface in the production line, using supplemental heat beneath the lens and added weight on the top inside surface. We have also been working with the LED driver company for improving their products towards the fourth generation with desired solutions on minor issues and for control of the yield rate in production and lowered costs for mass production. The ongoing roof test has continuously recorded data over the past winter session.

More details are listed as follows.

First, Figure 1 shows the problem of a defective signal light housing with concave lens surface, which is supposed to be flat as designed, but made defective during the production process in manufacturing. The concave lens surface made the assembly of the final signal light products difficulty, and could easily crack the inside glass disc used to support the 96 Fresnel lenses. The maximum tolerance of the error is 1.5-2 mm in depth. A portion of the produced housing samples have larger error. To solve this problem, we have been developing a remedying method in the laboratory for flattening the defective plastic housing produced with concaved lens surface in the production line, using supplemental heat beneath the lens and added weight on the top inside surface, as shown in Figure 2. A thermal lamp was installed in a box put below a safety glass, on which the defective lens sits. By adjusting the current running through the thermal lamp, and the distance between the lamp and the glass, we can adjust the temperature of the lens and its uniformity, as shown in Figure 2. The temperature on the lens surface and its distribution uniformity was monitored using four temperature sensors connected to a HOBO data logger. The data was recorded every 30 sec. Table 1 shows the test results with adjusted heights and duration of the heat exposure, resulting in different improvements on the lens center curved depth before and after the heating and pressure treatment.

Now we are communicating with the housing manufacturers to follow up on adoption of this heating and pressure treatment in their production process. We are waiting for new samples for further testing, if okay, assembly of final prototypes for field tests.

Figure 1 Signal housing with defective concave lens surface, which has a maximum tolerance of 1.5-2 mm in depth without impact on assembly, still under testing.

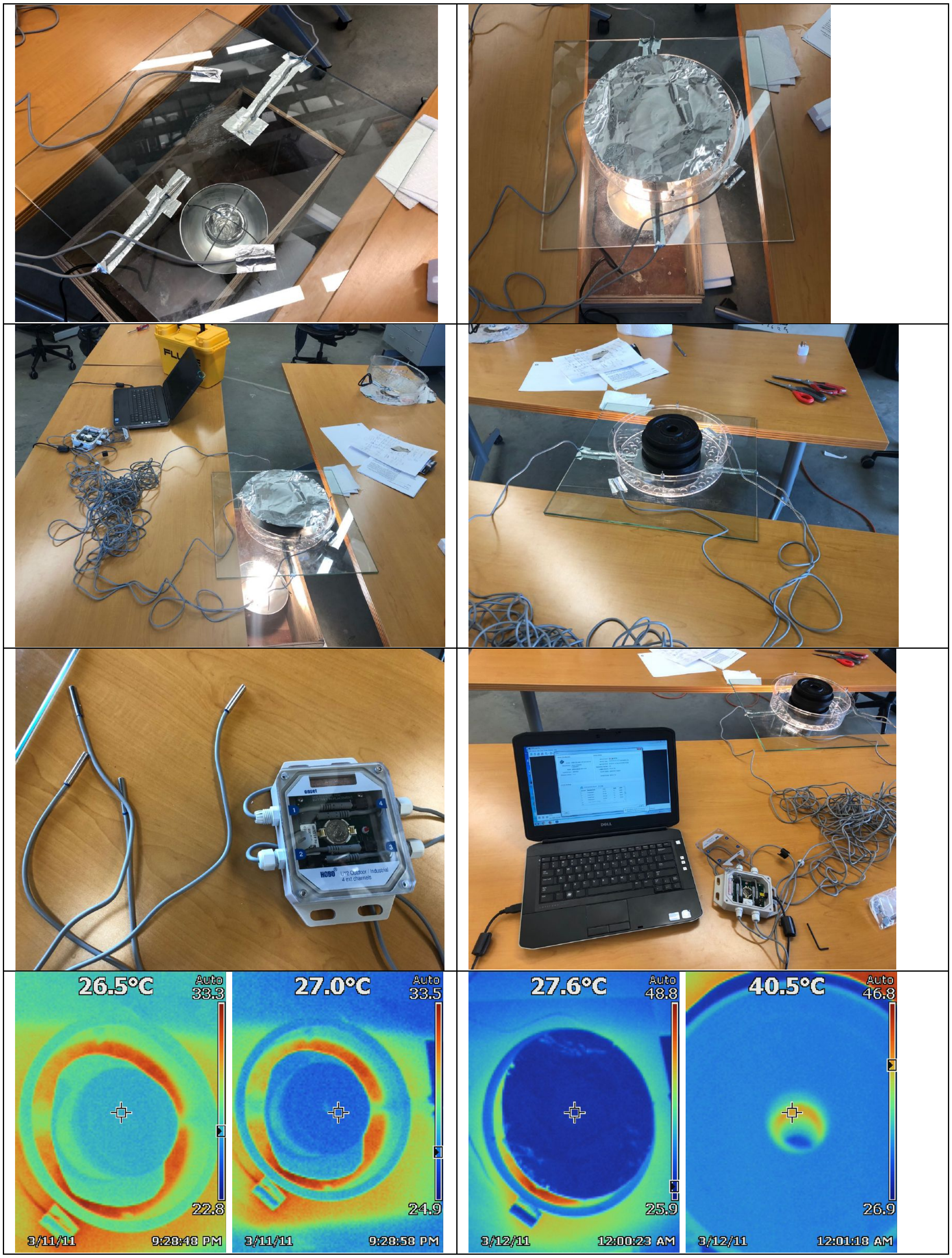


Figure 2 A remedying method in the laboratory for flattening the concaved lens surface, using supplemental heat beneath the lens and added weight on the top inside surface, a thermal lamp was installed inside a box below the glass on which the lens sits, the lens surface was monitored with four temperature sensors connected to a HOBO data logger.

Table 1 The results of the remedying method in the laboratory for flattening the concaved lens surface, before and after using the heating and pressure treatment

Test #	Heat power (W)	Time duration (hrs)	Lens surface avg. temp (F)	Distance (heat lamp to glass surface)	Lens center curved depth (before treatment)	Lens center curved depth (after treatment)	Reduced error
1	250	1.5	> 250	0.4 - 0.5 ft	burned	N/A	N/A
2	250	2	100	1.5 ft	5mm - 4.5mm	4.5 mm	no change
3	250	2.5	125	1.2 ft	5mm	3 mm	2 mm
4	250	3	150	0.8~1 ft	4.5mm	2 mm	2.5 mm

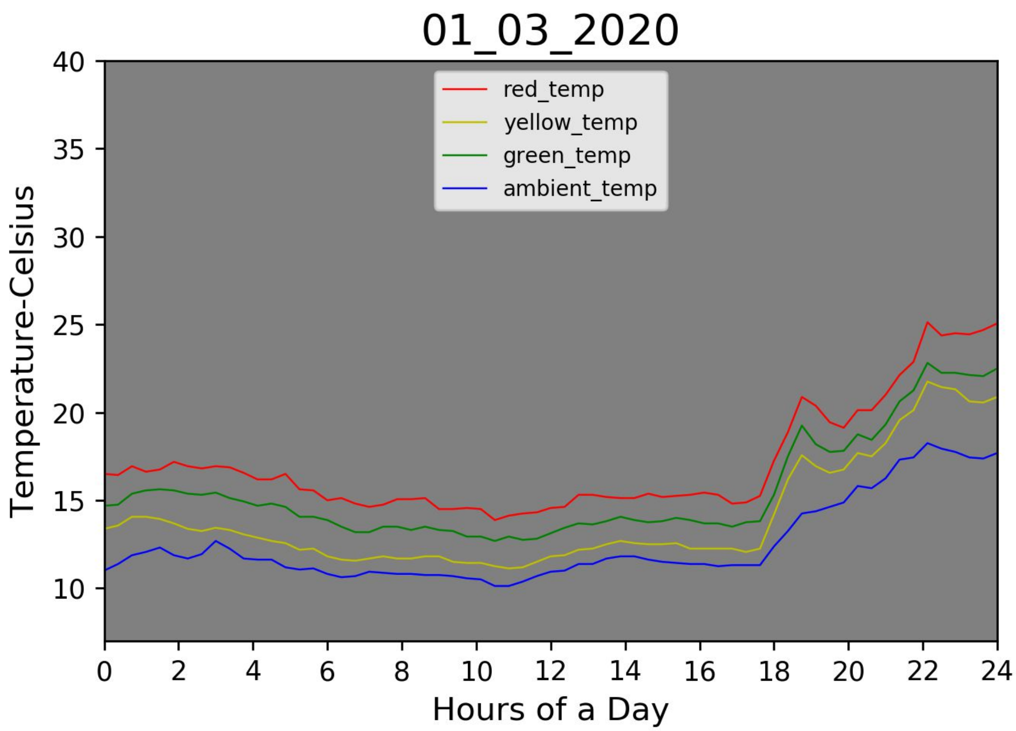
As shown in Table 1, it was found that the treatment can successfully reduce the concave length to tolerable depth of 2-3 mm, within 2-3 hours. Given longer exposure time in the heating and pressure treatment, it is possible the concave lens surface could be flattened with error less than 1 mm, but further tests are in need to validate that using more defective samples.

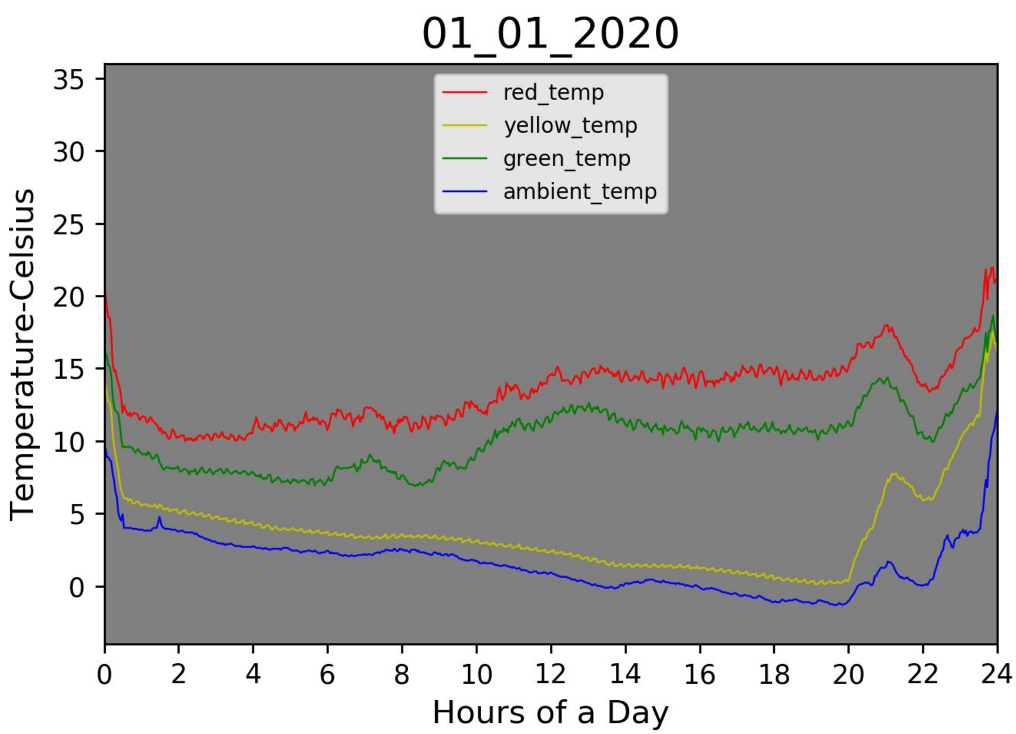
Second, we have also been working with the LED driver company for improving their products towards the fourth generation with desired solutions on the following two issues and for control of the yield rate in production and lowered costs for mass production. This work has been delayed due to the closure of the factory in china in the past quarter during the outbreak of the coronavirus. Now we have resumed the work.

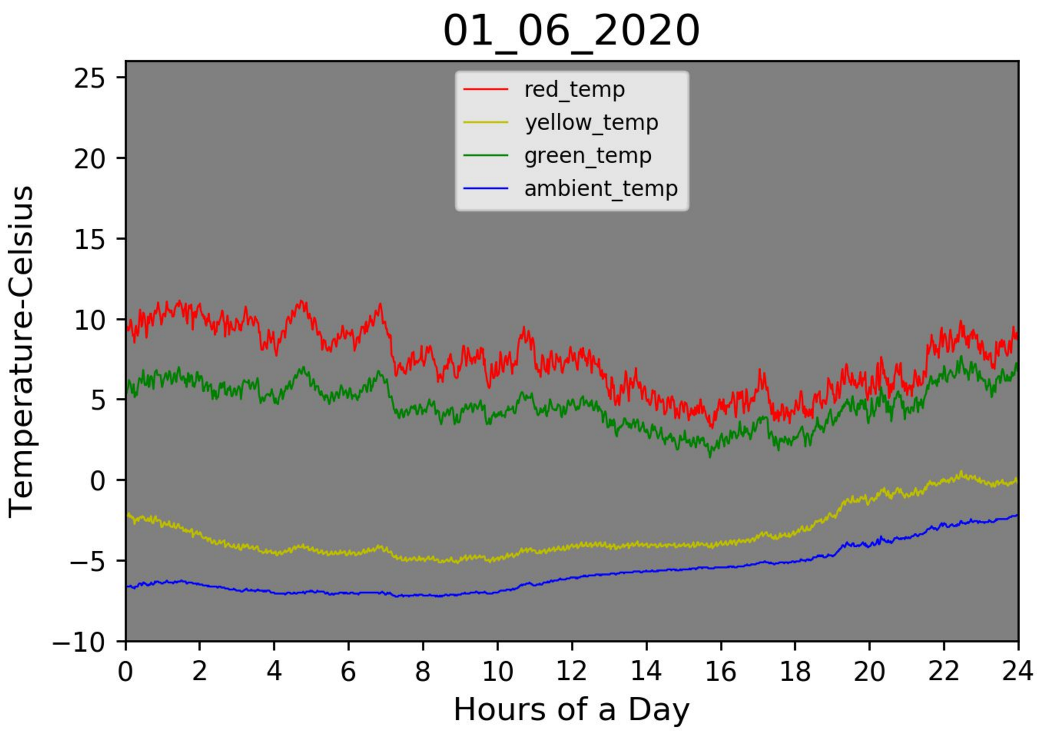
1) light power-up delay (the time delay between power on and signal light on) for about 0.5-1 second, especially for green signal light. ---- **Proposed Solution:** adjustment of MCU chips used in the driver to decrease the delay to only mini-seconds.
2) Unstable output performance of the drivers, due to unsecured soldering of wire connections by hands. ---- **Proposed Solution:** new products will be made on the automatic production line instead of hand-making (all previous samples due to small quantity were made by hands, not by machines). The unreliable soldering connection will be resolved, all new products will be aged by the standard procedure before shipping. This can largely improve the quality and reliability of new drivers, increasing the yield rate in production.

Thirdly, in the present quarter, the roof tests were undergone continuously (Figure 3). The monitoring system has continuously recorded data over the past winter session, as shown in Figure 4 for warm day on Jan 3rd (for comparison) and some extremely cold days in January and February. The performance of the self-de-icing signals were shown in the figures with the lens surface temperature of red, yellow and green lights. Photos of the lens were also taken by the monitoring system along with the temperature data, as shown in Figure 5, for some extremely cold days. It was shown no sign of snow accumulation or ices on the lens.

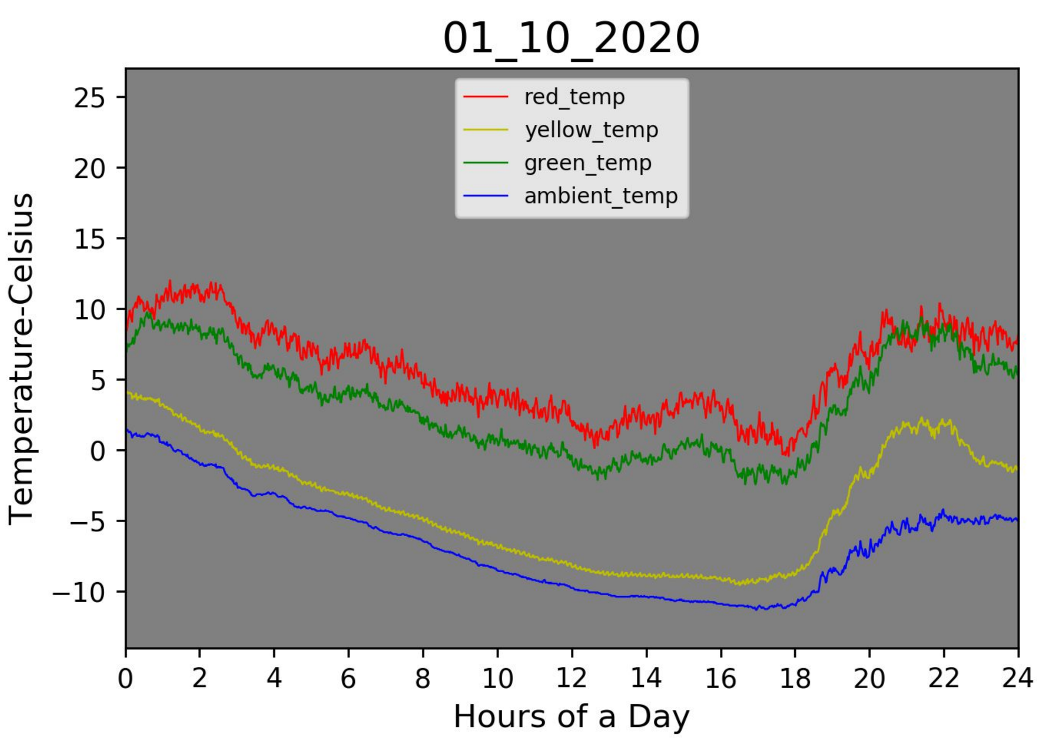
Figure 3 Roof test ongoing in winter.


01_03_2020
red_temp
yellow_temp
green_temp
ambient_temp
Temperature-Celsius
Hours of a Day

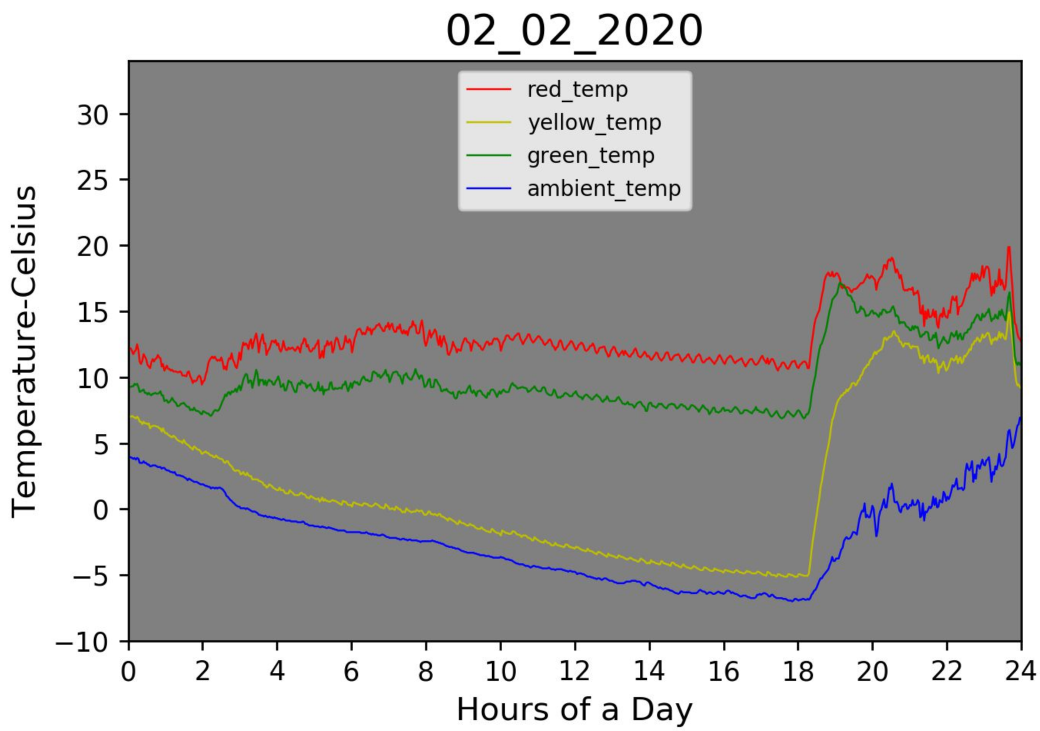

01_01_2020
red_temp
yellow_temp
green_temp
ambient_temp
Temperature-Celsius
Hours of a Day



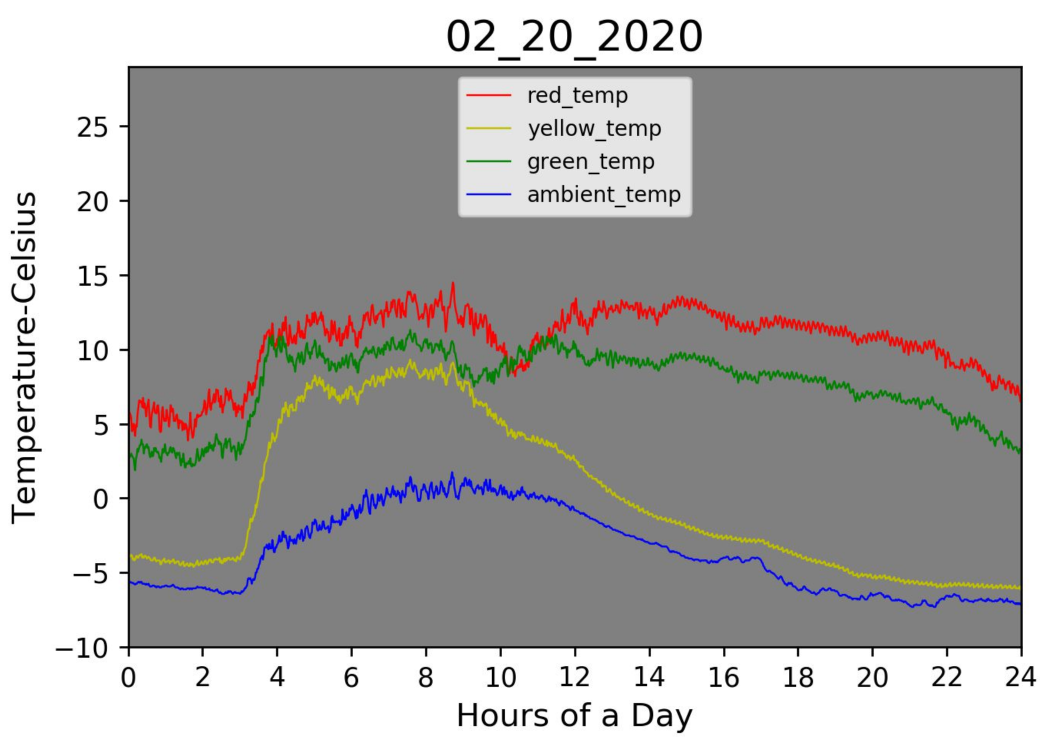
01_06_2020
red_temp
yellow_temp
green_temp
ambient_temp
Temperature-Celsius
Hours of a Day



01_10_2020
red_temp
yellow_temp
green_temp
ambient_temp
Temperature-Celsius
Hours of a Day



02_02_2020
red_temp
yellow_temp
green_temp
ambient_temp
Temperature-Celsius
Hours of a Day



02_20_2020
red_temp
yellow_temp
green_temp
ambient_temp
Temperature-Celsius
Hours of a Day

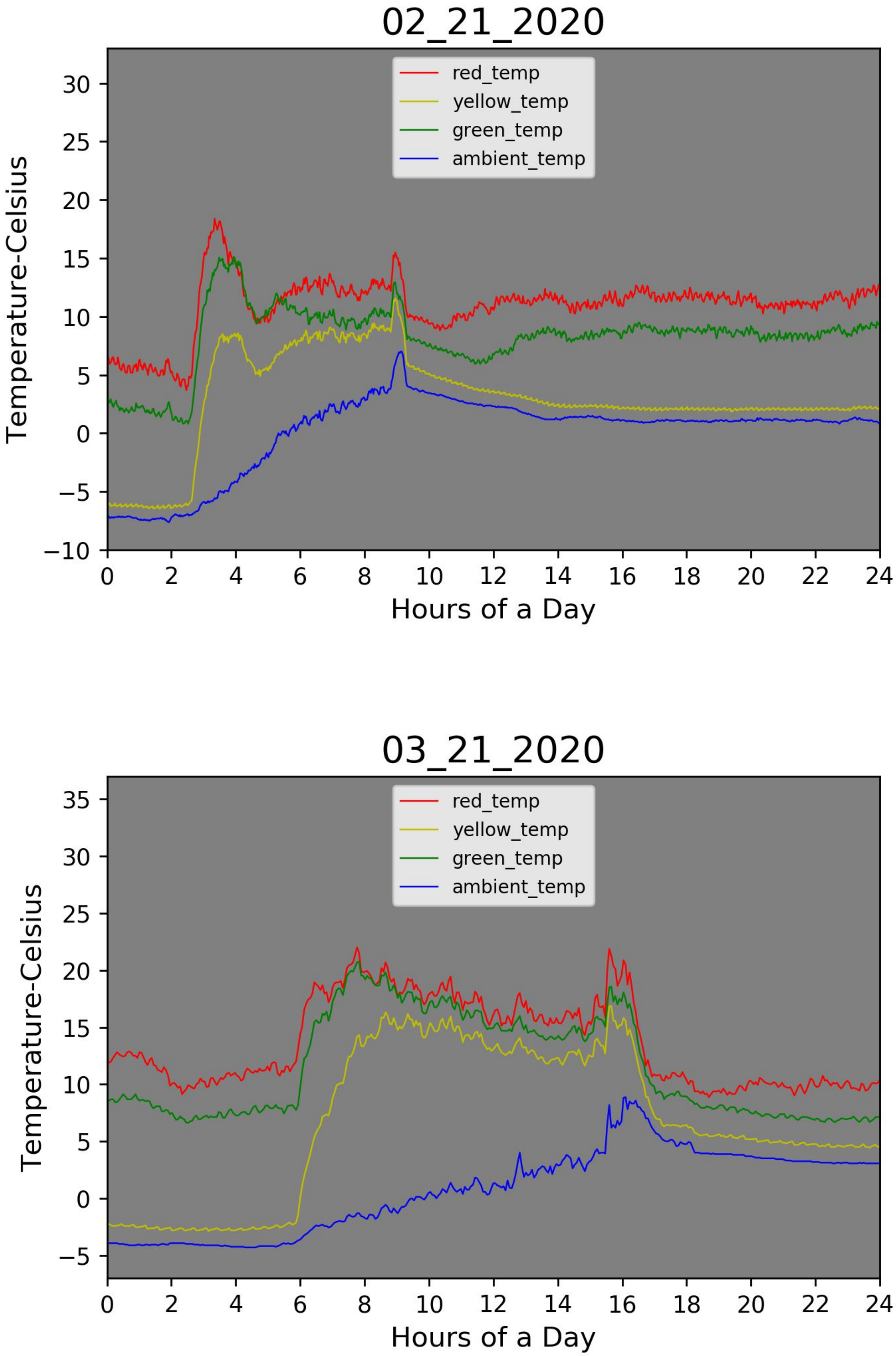
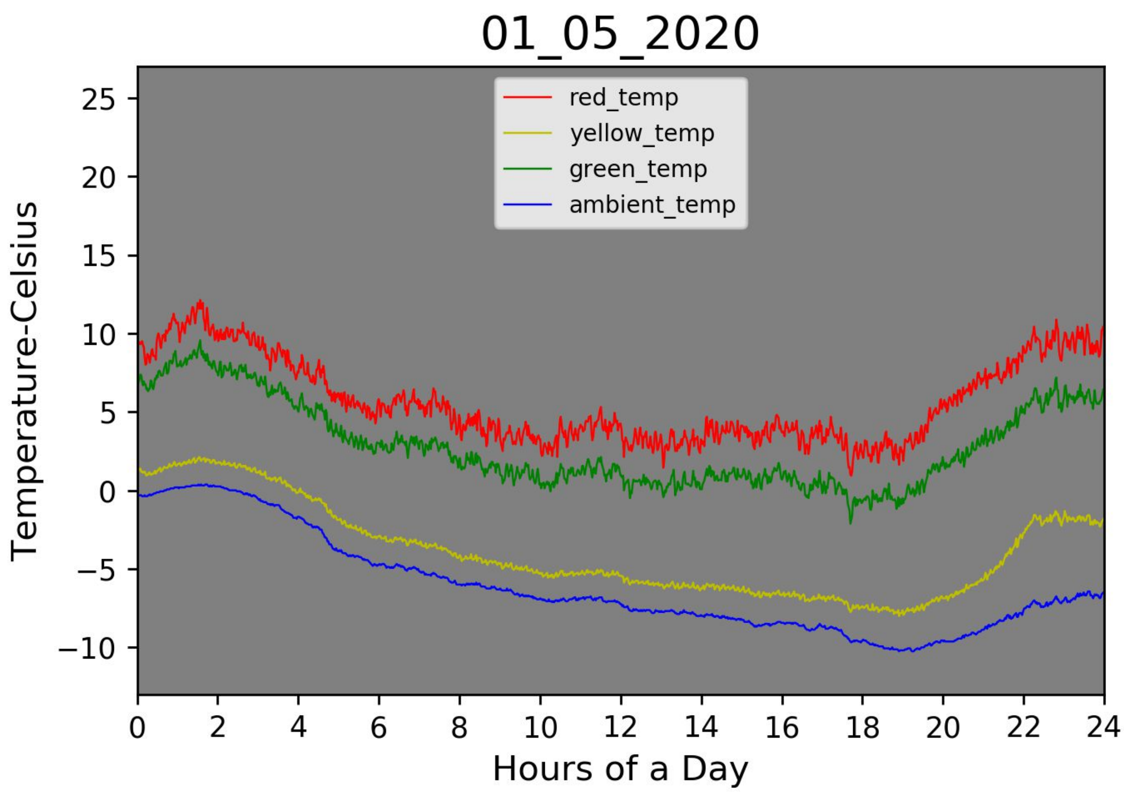
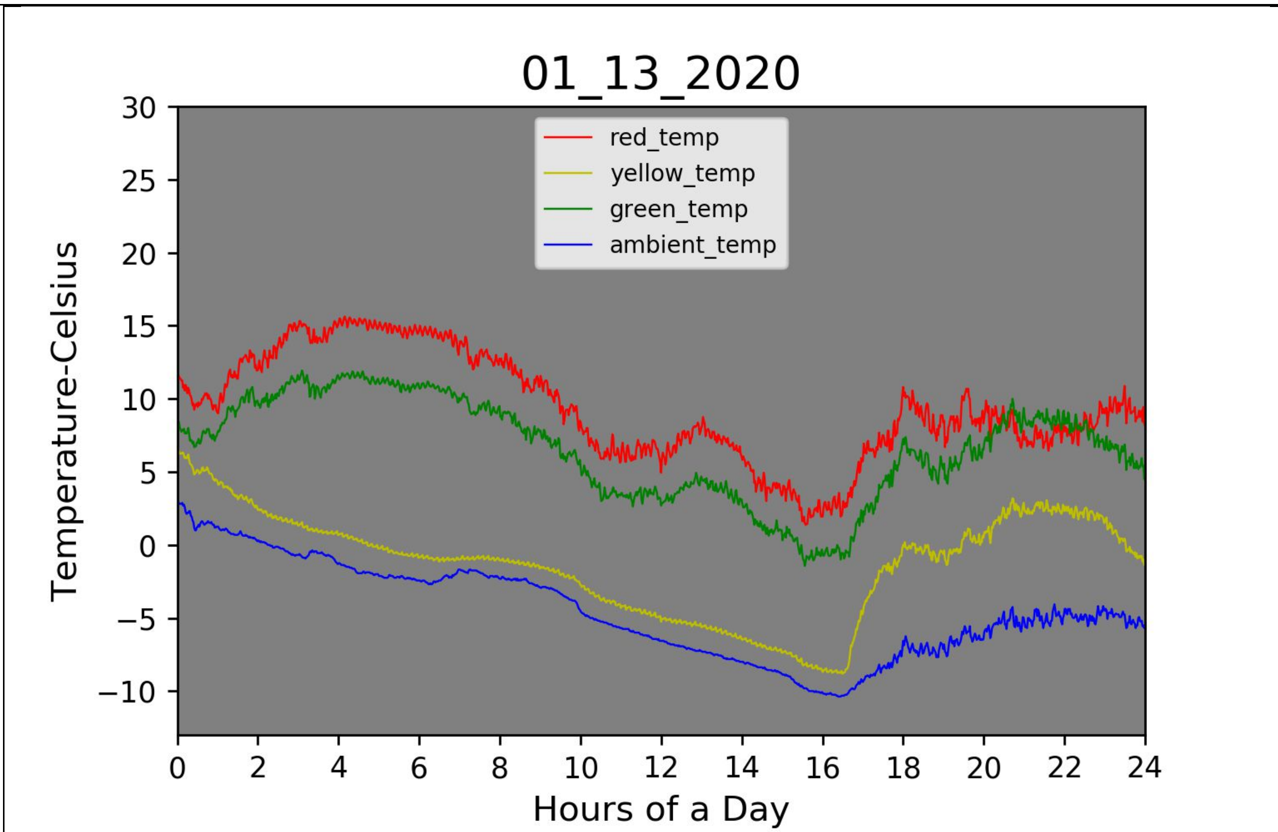


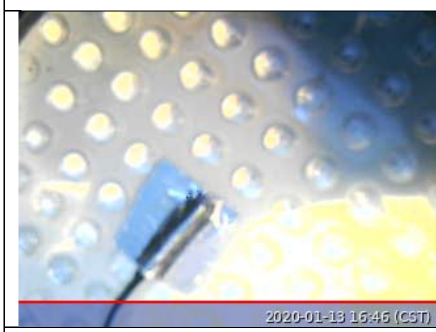
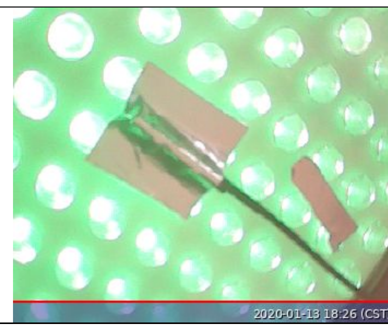
Figure 4 Roof test data during the warm and cold days, showing the performance of the red, yellow, and green signal lights under different weather conditions.



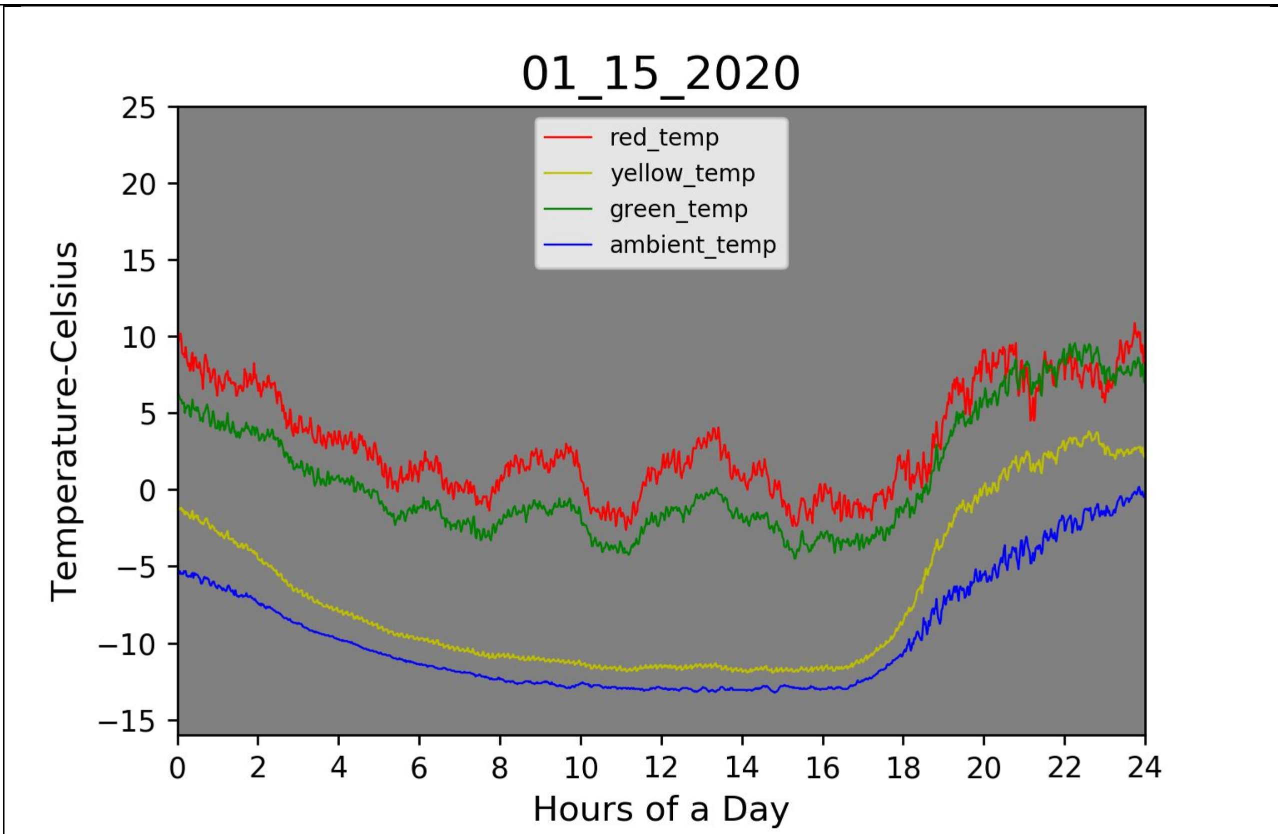
Red	Yellow	Green

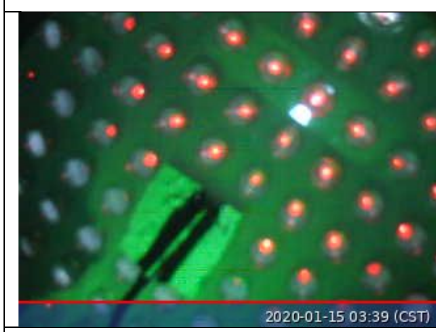
On Jan 5th



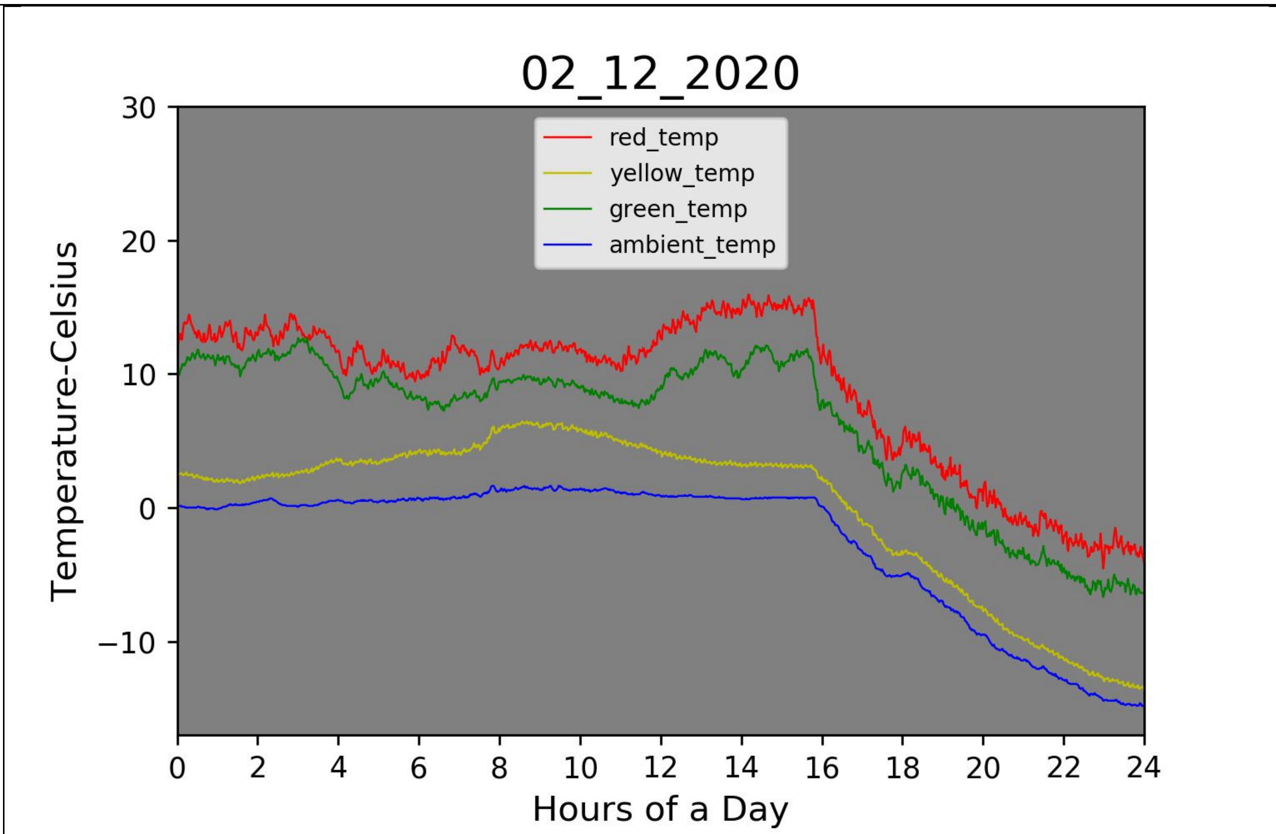
		
Red	Yellow	Green

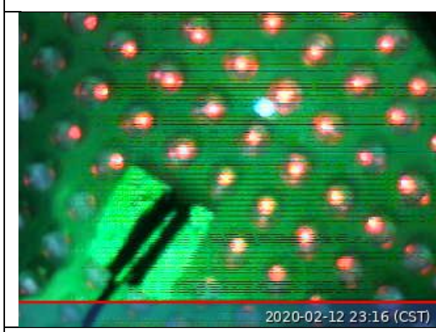
On Jan 13th



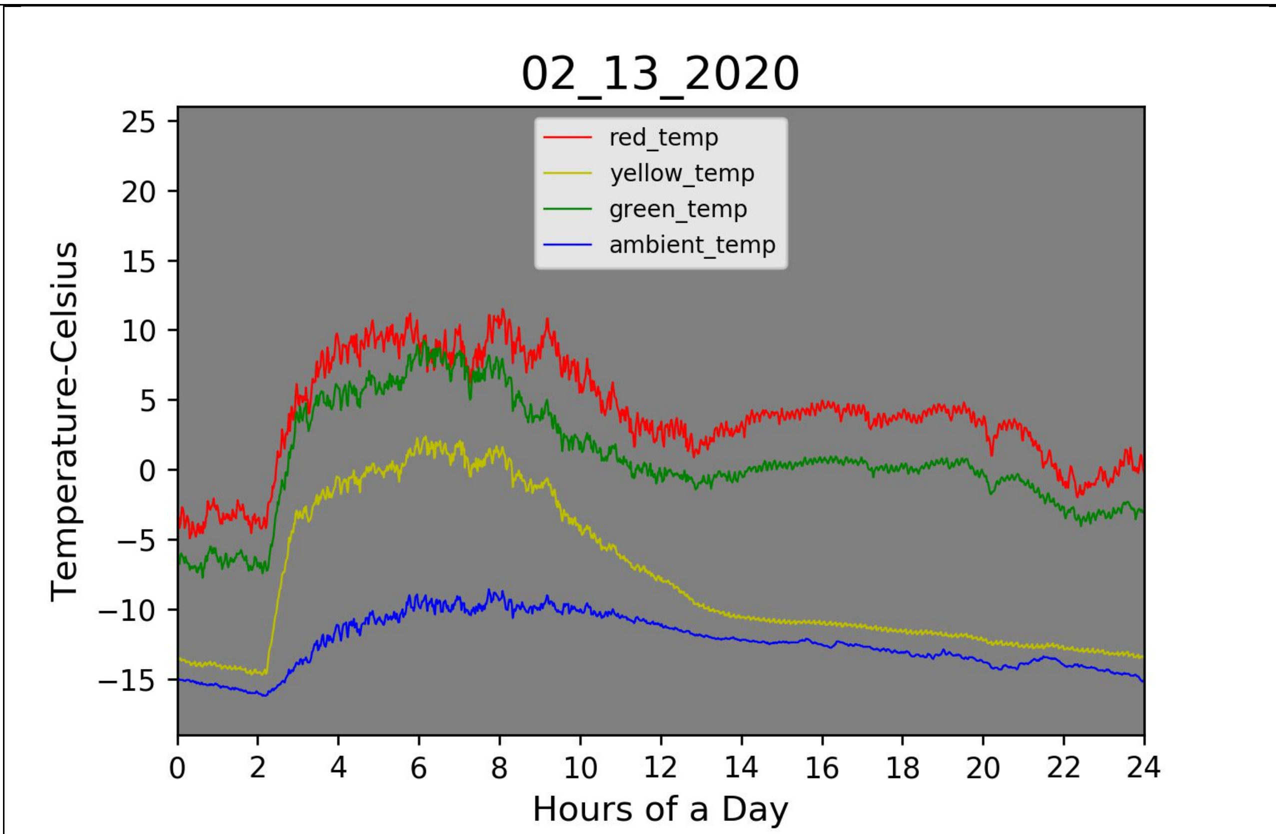
		
Red	Yellow	Green

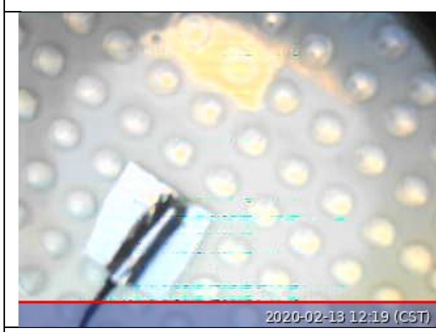
On Jan 15th



		
Red	Yellow	Green

On Feb 12th



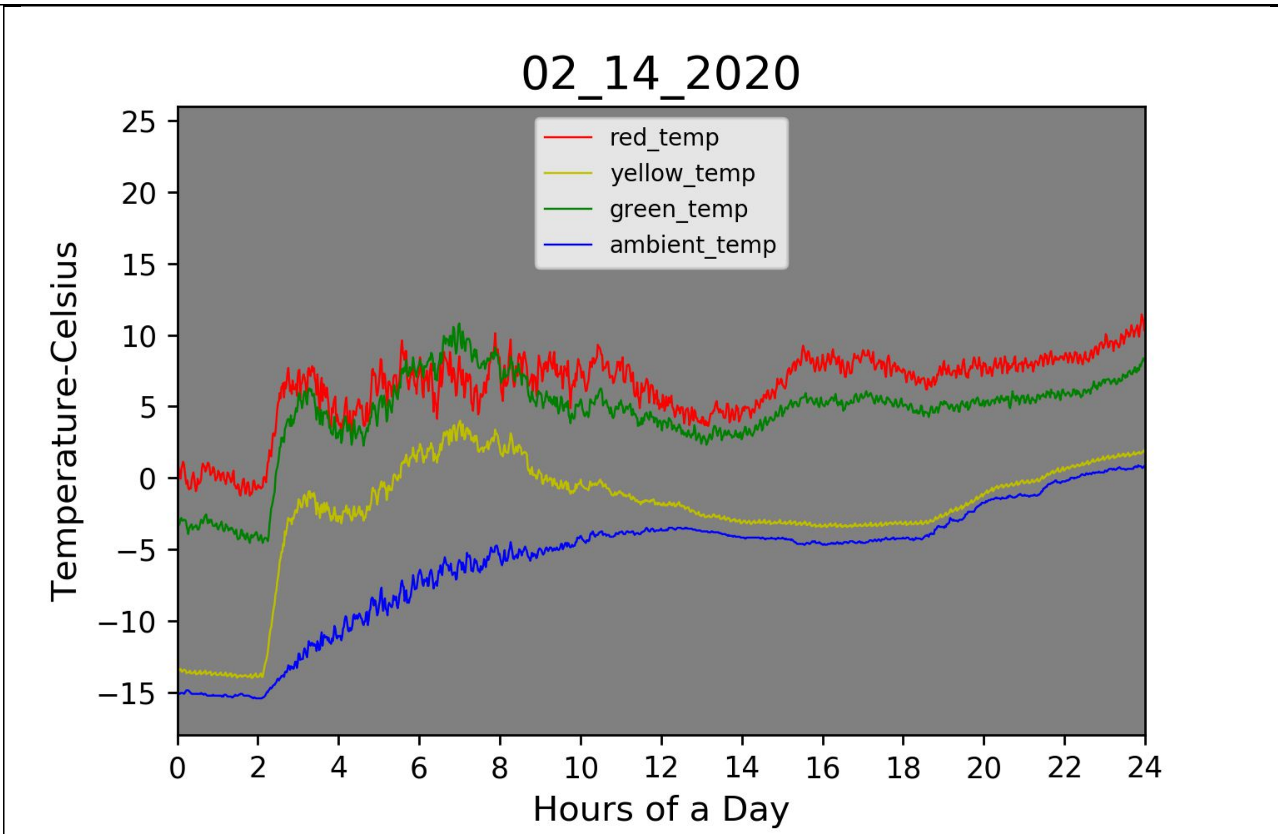


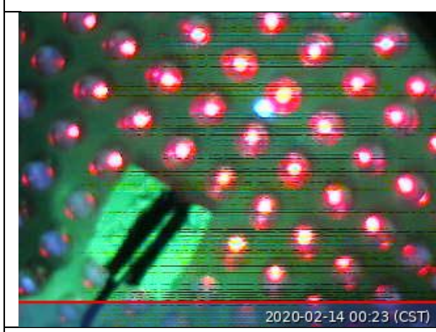
Red

Yellow

Green

On Feb 13th





Red	Yellow	Green

On Feb 14th

Figure 5 The first field test site in Kansas, at the intersection of County Rd 458 (or 1200 Rd) /US-59, where the selected signals are on the side of the road shoulder, facing north

Note that the ongoing field test in Kansas would have data in the same format as shown in Figures 4 and 5. However, due to the outbreak of coronavirus and the need to keep social distance, we did not contact the Lawrence signal crews to retrieve the data from the test site, which will be done at a later time when the virus situation is controlled and safe to do so.

Prototypes of the final products are in preparation for five more field test sites in California, Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland.

Anticipated work next quarter:

Starting from April 1, 2020 till June 30, 2020, we are planning to conduct the following tasks.

1. Working with the housing manufacturer to improve the manufacturing of the signal housing lens with flat surface, with tolerable concave error of 1-2 mm in depth, using the proposed heating and pressure treatment.

2. Communicating with the driver manufacturer to improve and custom make samples of the fourth generation of LED drivers, and test them in the laboratory for the field tests.

3. Checking the field performance of signals installed in the test site in Kansas.

4. Communicate with other states (in addition to Kansas) to locate the other 5 field test sites and the detailed plan on field installations. Depending on the time when the coronavirus is contained, field installation will be resumed. Field installation might need to be postponed due to the outbreak of the coronavirus.

Significant Results:

As of Dec 31, 2019, we have achieved the following significant results.

- This project was launched in Aug 2016 with six participating states (Kansas, California, Michigan, New Jersey, Wisconsin, and Pennsylvania) and an initial budget of $240,000. Maryland is expected to officially join the study by the end of this year with additional contribution of three years funding.

- An expert panel meeting was held in early March. Discussions were held on desired specifications of the prototype signals and possible field test sites as well as the field evaluation of the prototypes.

- Necessary equipment, components and insulation materials are being procured to develop and build the fully working prototypes of the finalized design and test for their thermal and lighting performance. We will continue to order LED drivers, electricity monitors, waterproof security video cameras, other mounting accessories and materials, etc., for monitoring the performance of the prototypes in the field tests in the upcoming winter season.

- Appropriate color LED modules, which are not available in the market, were designed in-house and custom-made with the aid of the industrial partner.

- Three preliminary prototype signals (Red, Yellow, and Green) of Type 1 have been developed in house, each deploying 26 custom-made color LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile". They are under laboratory testing for improvements.

- Tested the lighting and thermal performance of the preliminary prototypes of the Type 1 signal lights (Figure 1). Based on the test results, new design with a lot of changes and improvements has been finalized for final products.

- Finalized the design of Type 1 self de-icing LED signals using 96 custom-made mediate-power color

LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile". Designed in house and custom-made our own color LED modules (for each color R, G, Y) for making the fully working prototype signals of the first type with the aid of our industrial partner.

- Worked with the factories to optimize the mounting method of the custom-made LED modules on the 3-5 mm thick aluminum MPCB back plate serving as the passive heat exchangers of aluminum alloy for assembly.

- Custom-made three prototypes of the LED signals of Type 1 using 96 custom-made mediate-power color LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile", with regular paint coating, and finished laboratory testing for improvements and optimizations to finalize the design.

- Improved and custom-made three new signal light engines using 96 medium-power LEDs (0.25 Watt each) mounted in an array via "Heat Arrangement of LED Arrays in Low Profile" but with Tin coating (Figure 3) and tested them to improve the heating performance (to make faster heat transfer).

- Finalized the design of the signal lens that adopts a whole piece design with smooth and flat outside surface and integrated with 96 additional custom-made Fresnel lenses sitting inside the signal lens over each LED on the inside surface to focus the light serving as a collimator lens. Based on the testing results, the signal light engines with TIN coating may have superior thermal performance, however, further testing in the laboratory and field is necessary to validate the final choice.

- Identified and started custom-making the Fresnel Lens from HongXuan Optoelectronic company with diameter 15 mm and focal length 6 mm (model # HX-F015006).

- Developed the new whole-piece signal housing, new Fresnel lenses, LED drivers, and other accessories for the Type 1 self de-icing LED signal lights, with the aid of the industrial partner.

- Found and selected a qualified plastic molding company to custom make the three parts of the plastic housing of fully working prototypes of Type 1 signals that deploy 96 mediate-power LEDs via the architecture of "Heat Arrangement of LED Arrays in Low Profile". The new housing will be used for the new LED signal lights.

- The non-provisional patent application for the invention of Type 2 self de-icing signal light was officially approved by the USPTO and issued on Dec 26, 2017, patent No. US 9,851,086 B2.

- Started custom-making and modeling of the signal housing. Three samples were delivered for examinations and laboratory tests for necessary calibrations and further improvements.

- Started custom-making the LED drivers with desired specifications based on our test results. Seven LED drivers were delivered for sample testing.

- The custom-made signal housing is ready for production of products with possible minor adjustments for field tests in different states. Six improved samples have been delivered and thoroughly tested in laboratory and closed-setting tests on the roof.

- New type of screws for uses in the signal housing are self-designed and will be custom-made with Fastenal company.

- A company is custom making two improved and finalized types of LED driver, one for YELLOW and GREEN signal lights (output 0.8 A, maximum 30 Watts), the other for RED signal light (output 1.1 A, maximum 30 Watts). The new LED drivers have temperature Sensor control, when the temperature is above 4 degree Celsius, the LED driver output will be derated (For Yellow + Green LED lights, output current 0.5 A, approximately 17- 18 Watts; For Red LED light, output current min 0.6 A, approximately 15-16 Watts.) When the temperature sensor is turned off or failed for any reasons, the power output will be restored to 100% as default.

- The self-deicing signal lights have higher light output than the codes and standards required in all viewing angles from 0 deg to 70 deg as measured, even at the derated power output.

- We have been conducting a closed-course performance and reliability tests of the fully working prototypes mounted on the roof of the University of Kansas engineering complex - M2SEC building, in preparation for field tests.

- Seven states have officially participated in this project, including Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania and Maryland to provide support.

- A project addendum is proposed to conduct two additional field tests, one in Wisconsin and another one in a test site among Maryland, Pennsylvania, and New Jersey. A budget of $80,000 for the addendum is proposed to be spent starting on 5/18/2018 until the end of the project

- We have been continuously testing the closed-course performance and reliability of the prototypes previously mounted on the roof of M2SEC building. All signal lights were powered by the signal controller cabinet with real signaling time cycles (in a cycle length of 90 seconds, Red signal light ON for 50 seconds, Green signal light ON for 35 seconds, and Yellow signal light ON for 5 seconds. The temperature data were recorded every 10 seconds continuously over the entire test period, which will be continuously conducted over both winter and summer seasons in 2019.

- We have designed and custom made new types of screws to improve the connection strength of the screws integrated with the plastic housing. This type of screws are finalized products to be used in all finalized plastic housing.

- We have designed and custom made two types of LED drivers, including one type of custom-made LED driver for **red signal light** (input: 100-240 VAC, output: 0.6-1.1 A, max 30 W), and a second type custom made LED driver for **green/yellow signal light** (input: 100-240 VAC, output: 0.5-0.8 A, max 30 W). Both types of LED drivers are now integrated with a remote temperature sensor for controlling the power output in light of the ambient air temperature. An on/off switch is designed for temperature controls in winter and summer modes which could override the operation of the temperature sensor.

- We have accordingly improved and finalized the plastic housing of the fully working prototype signals of Type 1 with changes/improvements listed below, with assist of the plastic molding company — Eco Molding. Eco Molding company has custom made seven samples of the finalized new plastic housing for validations tests before actual product production.

- We have produced 60 pcs of the finalized LED engines with the aid of the industrial partner, ready for the upcoming field tests.

- We have also updated and custom made 60 pcs of glass disc which have four small mounting holes removed on the edge (the original glass disc had 8 mounting holes).

- We also custom made plastic mounting bars for mounting the glass disc to the LED light engine.

- We are working on getting improvement on custom-made Fresnal lens model number HX-F0150115 (diameter 15 mm, thickness 2.0 mm, focal length 11.5 mm) to increase tolerance of the thickness (approximately 1.8 – 2.1 mm) while reducing the unit cost.

- We are in preparation for field tests. Three fully functional prototypes of the fourth generation were mounted on a signal pole on the roof of an engineering building, powered by a traffic control cabinet for closed-course performance and reliability tests.

- Three more fully functional prototypes of the fourth generation were also tested in a well-controlled cold room for the performance of the ambient temperature sensor connected to the LED driver for switching full/derated power output. Based on the test results, we are adjusting the power output of the LED drivers. We are also making minor adjustments of the signal housing for quick assembly of the real products. Results have been used to evaluate the readiness of the prototypes for field tests starting in next quarter.

- Corrected some problems and resolved issues of the custom-made LED drivers, including (1) decreased the size of the power connector of the temperature sensor, (2) decreased the length to 6 mm, (3) changed to more reliable single switch, (4) enlarged the inside size of the installation hole to 6mm x 4.5 mm, (5) changed the final designed output current of Yellow/Green LED drivers to 0.40 A (derated) /0.84 A(full output), (6) changed the final designed output current of Red LED drivers to 0.60 A (derated) /1.1 A(full output), (7) improvements on temperature measurement accuracy, redesigned logic circuits, and changes of electronic parts used on the LED PCB boards.

- The signal housing of the fourth generation LED signal lights was revised for quick assembly. We have received the new prototypes of the housing with desired changes, which were tested in the laboratory with satisfactory performance.

- Other parts like glass mounting discs have also been improved in house for enlarging the installation holes to fit the new housing.

- Additional vendors for Fresnel lenses were contacted for lower unit price with higher quality control than the current lens vendor. Based on the lab test results, a total of 5000 PCS of new Fresnel lenses (**Model #1511**) were ordered from the new vendor for field tests.

- Based on the lab test results on the second generation of LED drivers, a total of 21 pcs of the third generation of LED drivers were ordered for lab tests, in preparation for the field tests.

- A total of 21 new LED drivers of the third generation for the field tests were made and are under testing in the laboratory for their field performance and any possible further improvements in need for control of the yield rate in production.

- A new proposal was approved on extended work with increased total project cost of $360K and extended new end date of June 30, 2021.

- Field monitoring systems powered by Raspberry 3 B+ motherboard, fitted with three cable cameras used to monitor three signal lights (Red, Yellow, Green) in each unit, four temperature sensors used to record the lens' surface temperature of the three signal lights (Red, Yellow, Green) and the ambient air temperature, USB flash drivers used to store the year around test data (pictures and temperature dataset), power supplies, and mounting accessories, have been custom built in house and under testing in the lab and on the roof, which will be mounted at each field test site for year-around real-time monitoring and data recording of the new signals to be tested in the field.

- New fully working prototypes of the signal lights for field tests have been assembled and are under thorough final tests in the laboratory in preparation for upcoming field tests.

- A total of 21 new LED drivers of the third generation were tested for their field performance and further improvements needed for the control of the yield rate in production. Based on the test results, the third-generation LED drivers may need further improvements towards the fourth generation, which will resolve two issues: 1) light power-up delay (the time delay between power on and signal light on) for about 0.5-1 second, 2) Unstable output performance of the drivers, due to unsecured soldering of wire connections by hands.

- The field monitoring system consisting of a Raspberry PI computer, three cable cameras, four temperature sensors, USB flash drivers, power supplies, and mounting accessories, was built in-house and continuously tested in the laboratory and on the roof for field installation. The system will be mounted at every field test site for year-around real-time monitoring and data recording of the new signals.

- The first field test site was set up in Kansas at the intersection of County Rd 458 (or 1200 Rd) /US-59. All new equipment including the performance monitoring system for data recording were installed on side signals facing north and already survived the first snowstorm in December.

- More prototypes of the final products are in preparation for other test sites. Seven states (Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland) are participating in field testing and evaluation of the prototypes.

- A remedying method in the laboratory for flattening the concaved lens surface, using supplemental heat beneath the lens and added weight on the top inside surface, a thermal lamp was installed inside a box below the glass on which the lens sits, the lens surface was monitored with four temperature sensors connected to a HOBO data logger.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

None.