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.

<table>
<tr><td colspan="2">Transportation Pooled Fund Project Number
TPF-5(351)</td><td colspan="2">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 1 – December 31)</td></tr>
<tr><td colspan="4">Project Title: Self De-Icing LED Signals</td></tr>
<tr><td colspan="4">Project Manager: Carla Anderson   Phone: 785-296-0357   E-mail: Carla.anderson@ks.gov</td></tr>
<tr><td colspan="4">Project Investigator: Hongyi Cai   Phone: 785-864-2597   E-mail: hycai@ku.edu</td></tr>
<tr><td>Lead Agency Project ID:
RE-0721-01</td><td colspan="2">Other Project ID (i.e., contract #):</td><td>Project Start Date:
August 15, 2016</td></tr>
<tr><td>Original Project End Date:
August 2019</td><td colspan="2">Current Project End Date:
December 2021</td><td>Number of Extensions:
2</td></tr>
</table>

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	$337,504.62	92%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$6,255.23	$6,255.23	2%

Project Description:

This pooled fund project will develop and demonstrate new self-de-icing LED signals for highway signalized intersections 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.

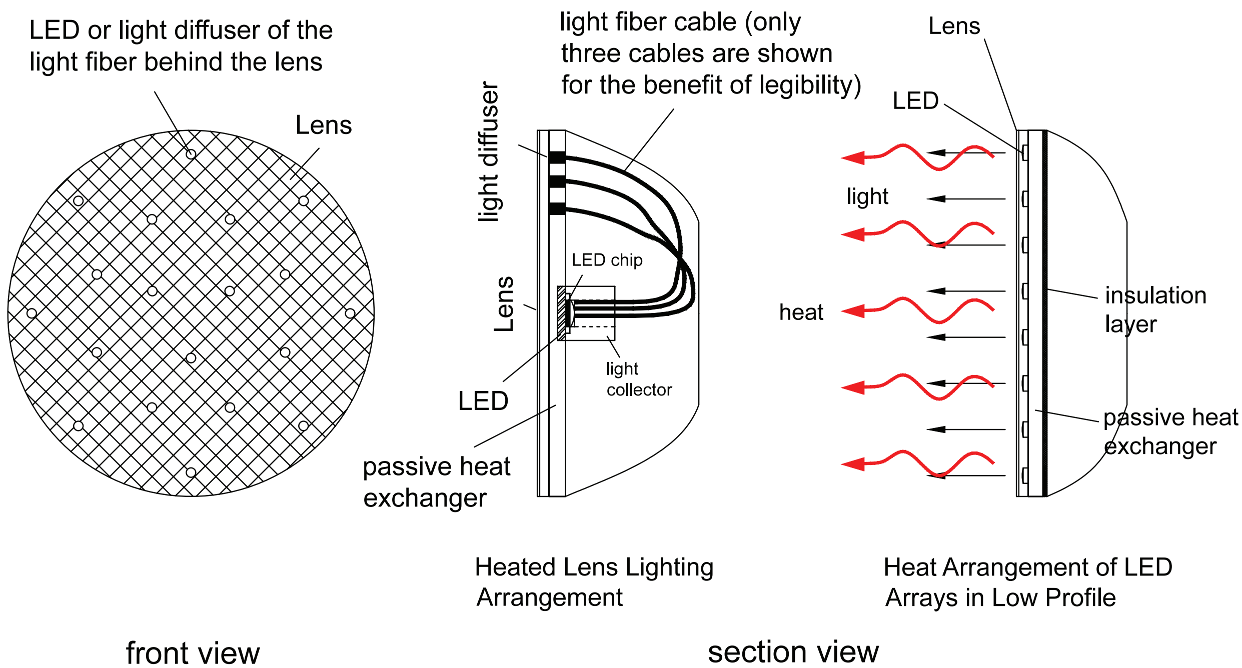


Figure 1 The concept of the self-de-icing LED signal light, which adopts new architecture of “Heated Lens Lighting Arrangement” or “Heat Arrangement of LED Arrays in Low Profile”

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. 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 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, 2021 – Mar 31, 2021) of the project period, we have the following accomplishments.

In the present quarter (Jan 1, 2021 – Mar 31, 2021), first, the new fresnel disc with 96 small fresnel lenses integrated on it has been custom-made in the factory through injection mold, 20 samples have been delivered to us for inspection and tests. The test results shown the lighting performance has passed the code requirements, the thermal performance is also good. However, the samples have a problem fitting in the house base. Among the 96 fresnel lenses, four of them do not fit the niches in the housing, slightly offset by 0.5-1.2 mm. Ten more fresnel lenses also offset by 0.3 mm but they still fit in the niches of the housing without a problem. The problem was found with the injection mold of the new fresnel disc, which was made with the wrong drawing that shall be mirrored. After long discussions and negations, desired corrections of the injection mold have been made, the factory has made two new corrected samples, already shipped them to us for inspection and testing. We are waiting for testing them. Once the quality and design is confirmed, in total 80 new samples have been ordered and will be shipped out to us for field tests in summer. The new fresnel disc with 96 small fresnel lenses integrated on is deemed a more cost-effective solution than using separate 96 fresnel lenses, and also as an alternative solution to the problem of uneven housing lens. The new fresnel lens disc is made of the PC material Markrolon 2807, same as the housing for UL certificate. Once the corrected new 80 fresnel discs are received, we will start making the 5th generation of signals to be used for field test in four more test sites this coming summer.

Second, we have prepared four extra sets of field remote monitoring kits with mobile communication information device to remotely send signal performance data back to the laboratory on daily basis for real-time performance monitoring, and thoroughly tested them. They will be used in the upcoming four field test sites in different states in summer.

Third, for the Lawrence test site, we solved a problem related to the data collection and performance remote monitoring system (not part of the self-de-icing signal lights) in the present quarter. The problem was the cable camera used to record the real-time image of the RED light signal lens failed after being exposed to the environment in the past two years. We visited the Lawrence test site with the Lawrence signal crew on Feb 25 and replaced all three cable cameras. We also found loose mounting of temperature sensors on the red and yellow signal lenses, which were mounted by the electrician last time, and corrected their mounting. Such loose mounting explained the recorded lens' surface temperature drop of the red and yellow signal lights close to the ambient temperature in late January and early February. After the field visit, the ongoing field test in the Lawrence test site is functioning normally and data have been automatically collected on daily basis. The performance data retrieved from the Lawrence test site show the self-de-icing signals have been working properly, especially for the green signal light which has the longest power on time.

Fourth, we have started writing a manual to be used by signal crews of different states for mounting the new self-de-icing signals and the corresponding data recording and remote monitoring system, for the upcoming field test site use.

More details are listed as follows.

Firstly, we have tested the lighting and thermal performance of the 20 new samples of the new fresnel disc with 96 small fresnel lenses integrated on it, which is made of Markrolon 2807 for UL certificate. Figure 1 shows the lighting performance of the 5th generation prototypes mounted with the new fresnel lens disc. The test results shown the lighting performance has passed the code requirements as listed in Table 2.

TABLE 1 Lighting performance of the fifth generation signal lights of different colors with derated/dimmed output and full output, respectively, all passed the code requirements of $I_{(-2.5°,\ 0°)}$

Tilting angle θ_{vert} (°)	Intensity (cd)					
	Red, Dimmed	Yellow, Dimmed	Green, Dimmed	Red, Full output	Yellow, Full output	Green, Full output
0	667.5	2088.2	1713.3	1277.2	3900.8	2740.9
0.5	668.1	2089.6	1721.3	1277.9	3903.4	2741.6
1	668.1	2091.6	1728.0	1281.9	3927.6	2747.6
1.5	671.5	2091.6	1733.4	1283.3	3932.3	2791.2
2	676.2	2089.6	1740.8	1288.0	3928.3	2818.1
2.5	**680.9 > 365 (code)**	**2087.6 > 910 (code)**	**1751.5 > 475 (code)**	**1300.0 > 365 (code)**	**3945.7 > 910 (code)**	**2827.5 > 475 (code)**
3	685.6	2088.2	1761.5	1301.4	3925.6	2832.2
3.5	691.6	2091.6	1772.3	1316.8	3932.3	2835.5
4	697.0	2093.6	1785.0	1328.2	3977.9	2838.2
4.5	708.4	2099.6	1801.8	1351.7	3988.6	2900.6
5	721.1	2109.0	1821.2	1394.6	4028.2	2932.1
6	741.9	2129.2	1873.6	1459.7	4173.1	2960.3
7	774.8	2163.4	1954.7	1518.7	4197.3	3127.3
8	821.7	2199.6	2027.2	1618.7	4311.3	3203.1
9	878.1	2208.3	2129.8	1597.2	3953.1	3407.7
10	873.4	2153.3	2127.1	1521.4	3725.0	3382.2
11	822.4	2021.8	1959.4	1338.3	3275.6	3115.2
12	752.6	1778.3	1845.4	1134.3	2667.8	2952.9
13	626.5	1452.3	1768.3	898.2	2048.0	2829.5
14	491.7	1178.6	1630.7	731.2	1744.1	2625.6
15	399.1	923.0	1343.0	668.8	1532.1	2162.0
20	145.6	437.4	463.5	256.2	760.7	737.2
25	102.6	301.2	313.9	188.5	551.4	502.4
30	82.5	232.8	249.5	150.3	416.6	404.5
40	57.7	159.0	173.7	117.4	318.0	276.4
50	53.0	133.5	143.6	77.8	193.9	232.8
60	63.1	155.6	177.1	75.8	185.1	285.1
70	23.5	88.5	113.4	50.3	188.5	180.4
80	8.0	48.3	58.4	21.5	74.5	92.6
90	3.4	20.8	28.2	12.1	59.7	45.6

TABLE 2 Peak minimum maintained luminous intensity values of $I_{(-2.5°, 0°)}$, measured at vertical off-axis viewing angle of $\theta_{vert} = -2.5°$ and horizontal off-axis viewing angle $\theta_{horiz} = 0°$, of signal lights with a lens diameter of 12 inches by color of the module as required by the code [10]

Light color	$I_{(-2.5°, 0°)}$ 300 mm (12" in diameter)
Red	365 cd
Yellow	910 cd
Green	475 cd

Figure 2 shows the thermal performance tested in the laboratory of the 5th generation prototypes, the temperature differences between the signal lens and the ambient were found very similar to the prior thermal test results as shown in Table 3, indicating the new fresnel lens disc would have similar thermal performance as the old configuration using glass disc and 96 individual fresnel lenses. Note that, because of the fitting problem found in the first 20 samples of the fresnel lens disc, the corrected fresnel lens disc is supposed to have better fitting and thus slightly better thermal performance than shown in Figure 2.

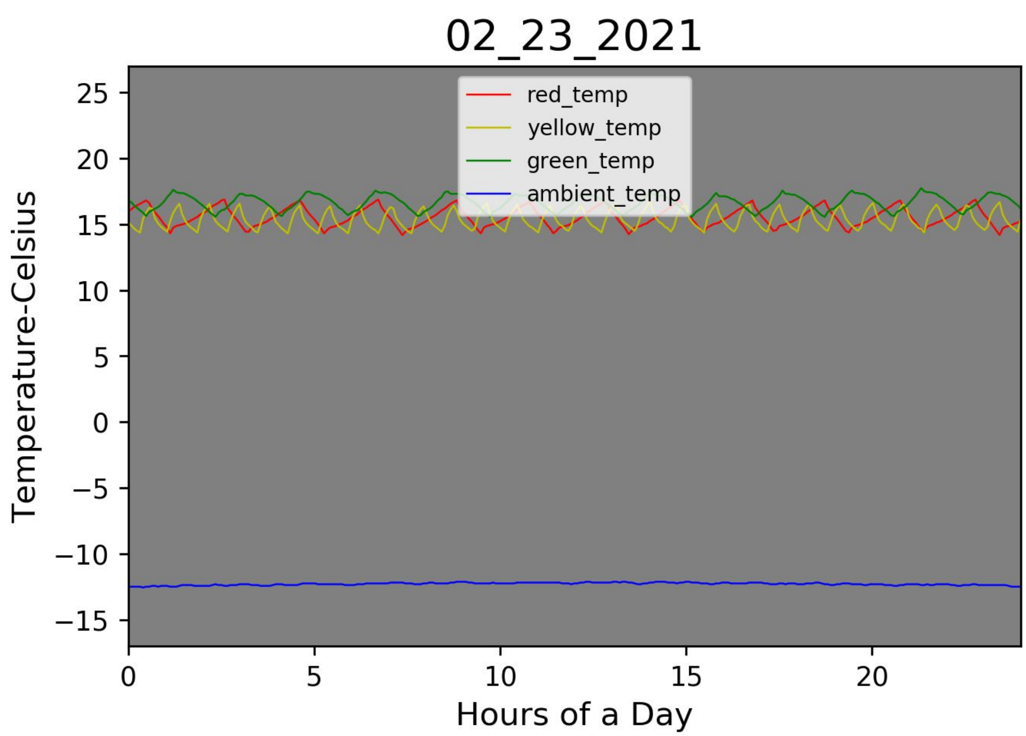


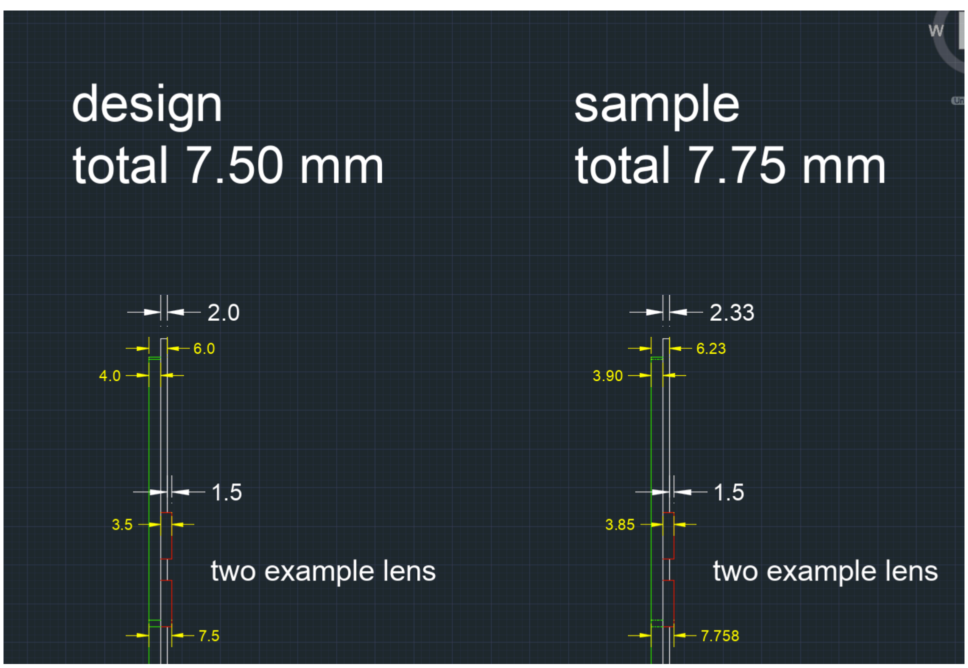
Figure 2 Thermal test results of the 5th generation self-de-icing signal housing, made of PC material Markrolon 2807, mounted with the new fresnel lens disc (rather than the old configuration in the 4th generation using glass disc and 96 individual fresnel lenses).

TABLE 3 Typical thermal performance of fully functional prototypes (R, G, Y) of the new signals in a freezer when continuously powered with 100% power output, tested before based on the 4th generation of signal lights (without using the new fresnel lens disc)

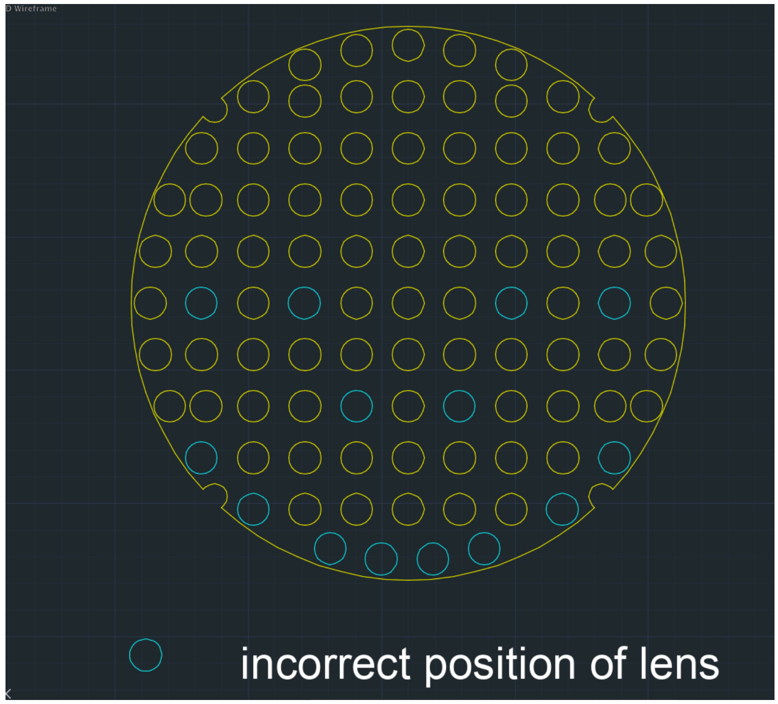
Test conditions	**Freezer, 3 signals tested together**	
Ambient Temp	Ambient air	21.5 ° F (-5.8° C)
Surface Temp	Green light (current 0.837 A)	76.5 ° F (24.7° C)
	Yellow light (current 0.838 A)	76.9 ° F (24.9° C)
	Red light (current 1.115 A)	72.8 ° F (22.6° C)
Temp Difference (Δ)	Green light (current 0.837 A)	Δ55.0 ° F / Δ30.5° C
	Yellow light (current 0.838 A)	Δ55.4 ° F /Δ30.7° C
	Red light (current 1.115 A)	Δ51.3 ° F /Δ28.4° C

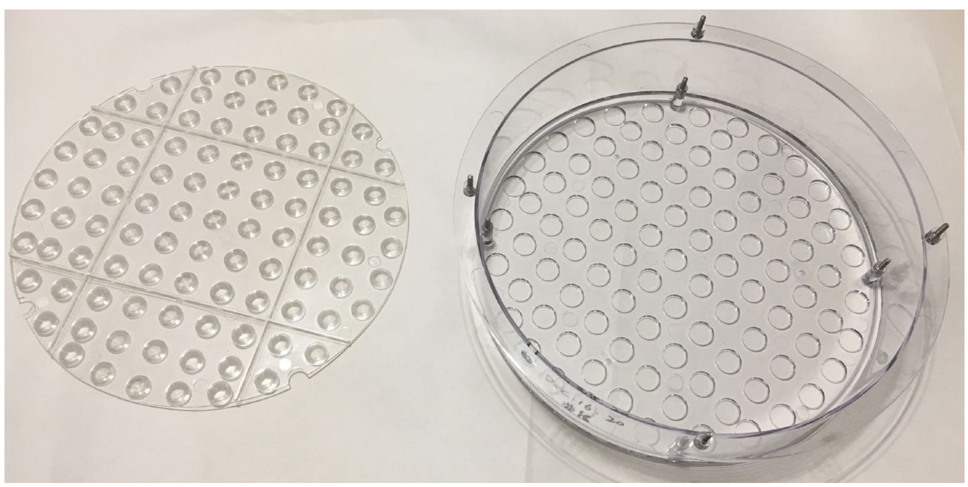
Secondly, as aforementioned, the 20 samples of the new fresnel lens disc have two problems for fitting in the house base. The problems are listed below, also shown in Figure 3a.

- The samples' dimensions are slightly different from the design, see Figure 3. The back beam's height was increased from the designed 2 mm to 2.33 mm, causing the total thickness of the sample increased from designed 7.5 mm to 7.75 mm. The solution is to maintain the new thickness of 2.33 mm of the board unchanged, but decreasing the height of the back beam from designed 4 mm to 3.5 mm, leading to a revised height of 3.5 mm, which can ensure the fitting of the fresnel lens in the housing.
- Among the 96 fresnel lenses, a total of 14 of them do not fit the niches in the housing, as shown in Figure 3b, especially the bottom four which slightly offset by 0.5-1.2 mm, as shown in Figure 3c. The problem was found with the injection mold of the new fresnel disc, which was made with the wrong drawing that shall be mirrored.

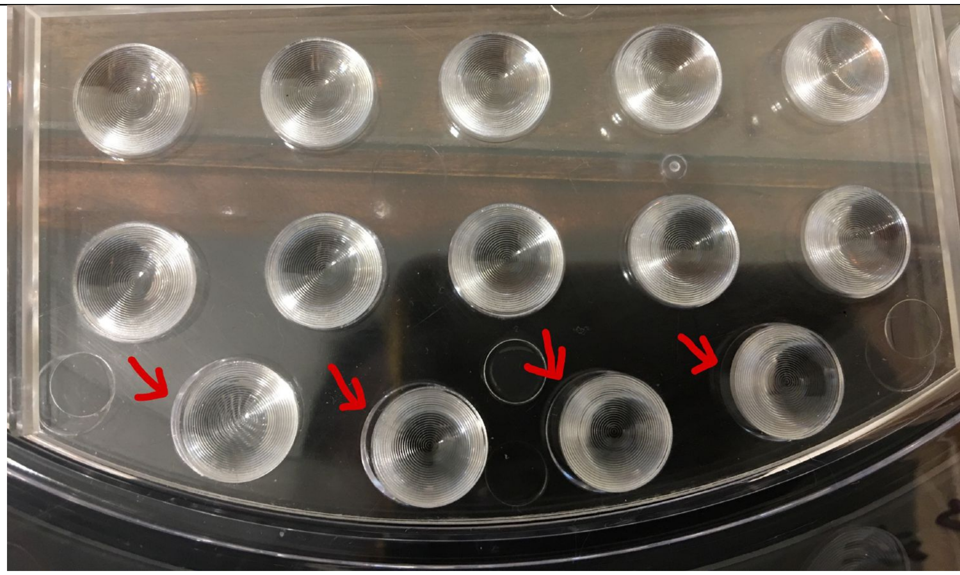


(a)





(b)



(c)

Figure 3 Two problems found in the first 20 samples of the new fresnel lens disc, which affected their fitting in the house base, leading to corresponding slightly different lighting and thermal performance.

Those problems have been addressed with corrections of the injection mold, the factory has made two new corrected samples, which are on the way to us for inspection and testing. Once the quality and design is confirmed, in total 80 new samples have been ordered and will be shipped out to us for field tests in summer.

Thirdly, in preparation for the upcoming four field test sites in different states in summer, we have prepared four extra sets of field remote monitoring kits, as shown in Figure 4, with mobile communication information device to remotely send signal performance data back to the laboratory on daily basis for real-time performance monitoring, and thoroughly tested them.

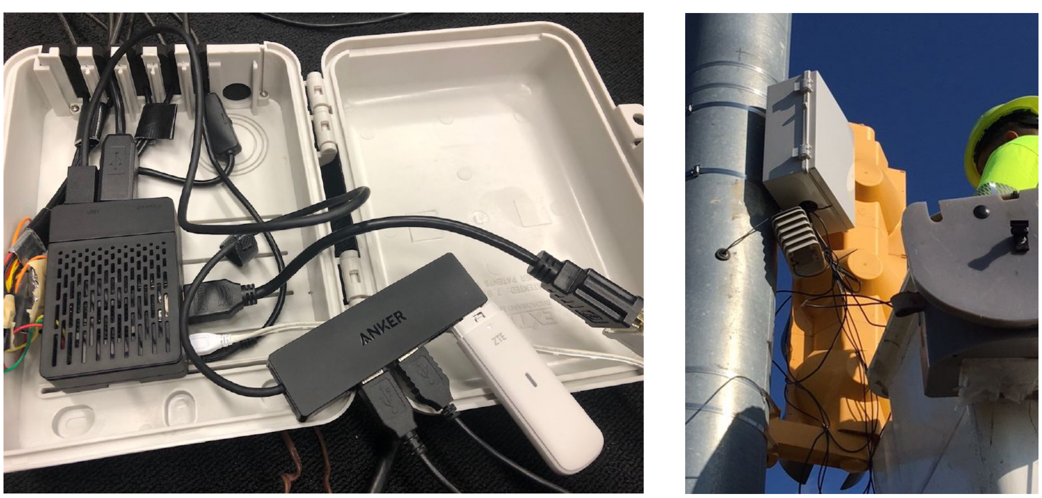
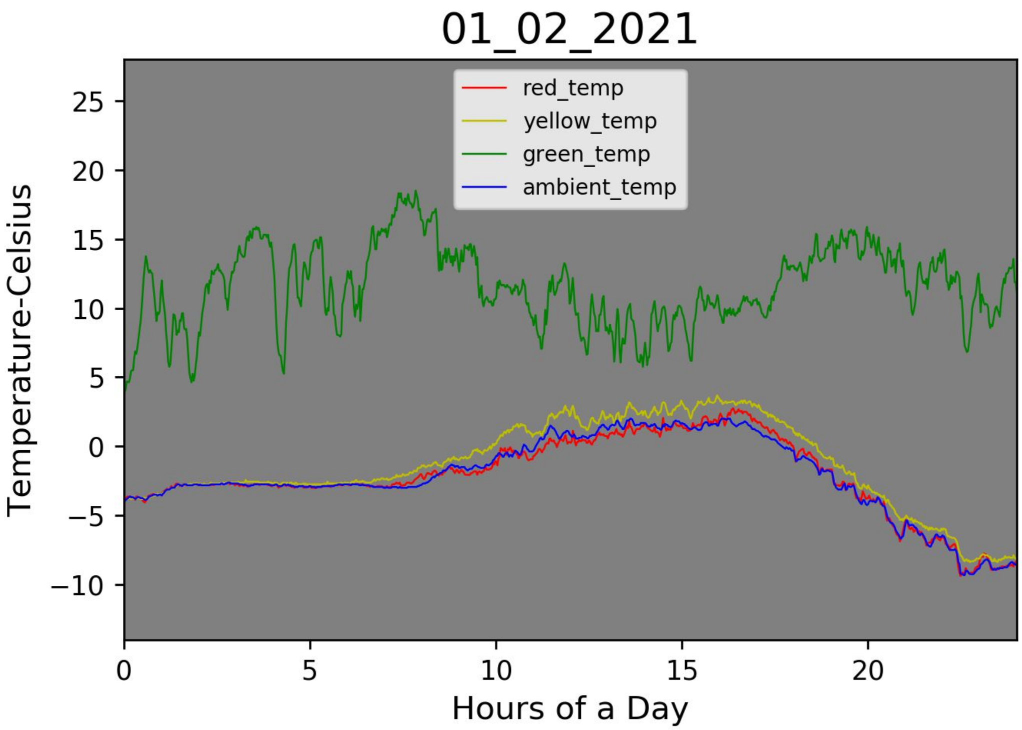


FIGURE 4 A remote field performance monitoring system, controlled by a Raspberry PI computer with a USB driver for recording data, which consists of three cable cameras, four temperature sensors, mobile communication device with monthly data plan (2 GB/month), power supplies, and mounting accessories.

Fourthly, as shown in Figure 5, we and the Lawrence signal crew stopped at the test site on Feb. 25th to replace all cable cameras used to record the real-time image of R/G/Y signals, which failed after being exposed to the environment in the past two years. We also re-mounted the otherwise loose temperature sensors on the red and yellow signal lenses. Such loose mounting explained the recorded lens' surface temperature drop of the red and yellow signal lights close to the ambient temperature in late January and early February, as shown in Figure 6 on those cold test dates before Feb 25th. On the other hand, in some windy cases, the ambient temperature could be higher than the yellow and red signal lens with very short signal on time, because the ambient temperature sensor is mounted inside a shade, which isolates the sensor from the wind. After the field visit, the performance data retrieved from the Lawrence test site show the self-de-icing signals have been working properly, especially for the green signal light which has the longest power on time, as shown in Figure 7 after Feb 25th.

Figure 5 We stopped at the Lawrence field test site on Feb 25th, with the Lawrence signal crew, to fix two problems related to the data collection and performance remote monitoring system (not part of the self-de-icing signal lights). We replaced the problematic cable cameras which failed after being exposed to the environment in the past two years. We also fixed the loose mounting of temperature sensors.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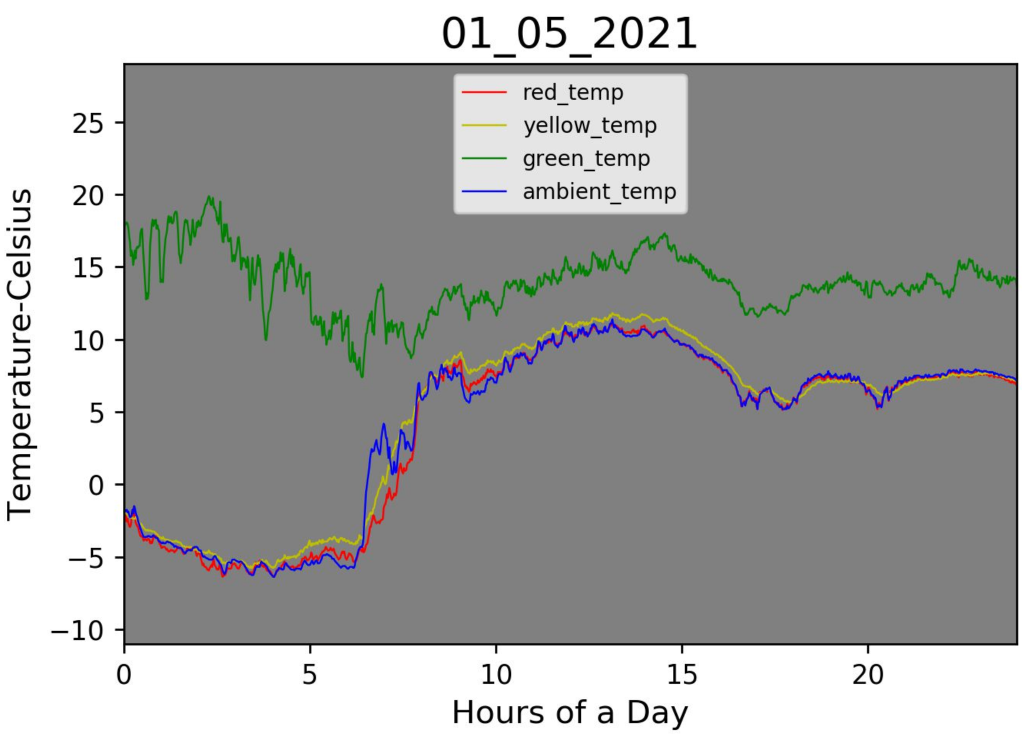
ambient_temp
Temperature-Celsius
Hours of a Day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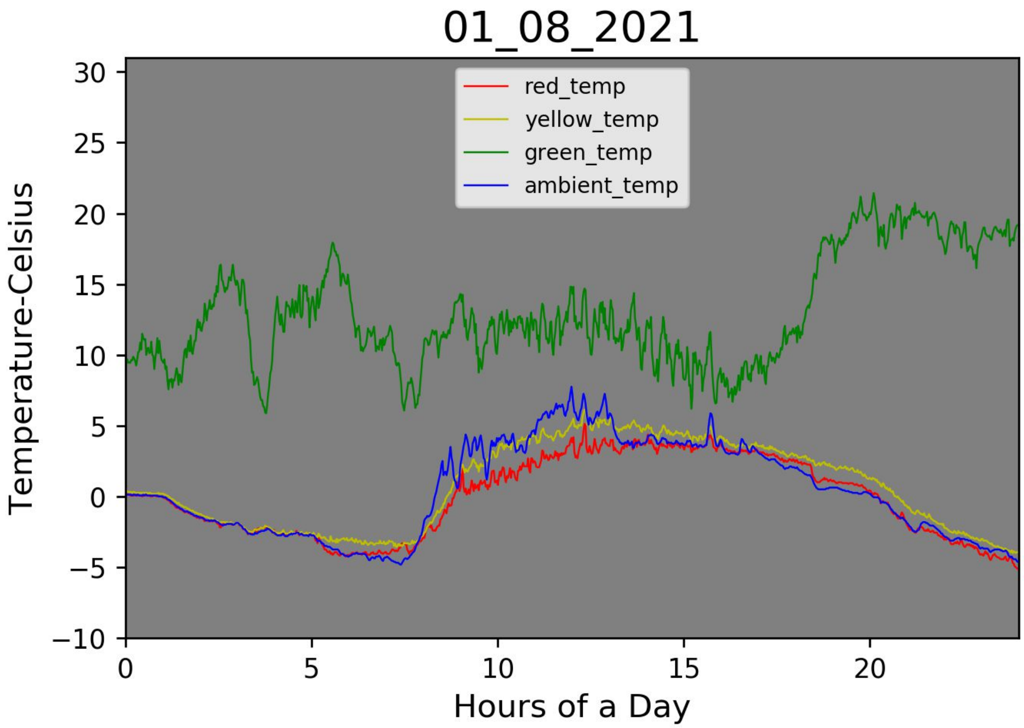
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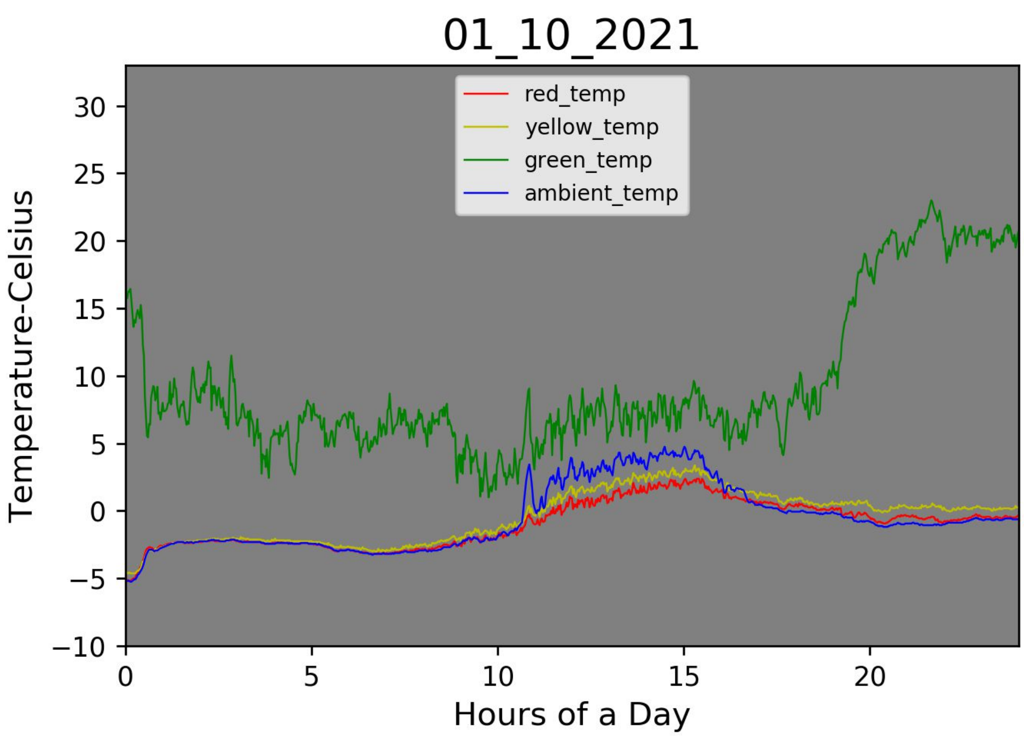
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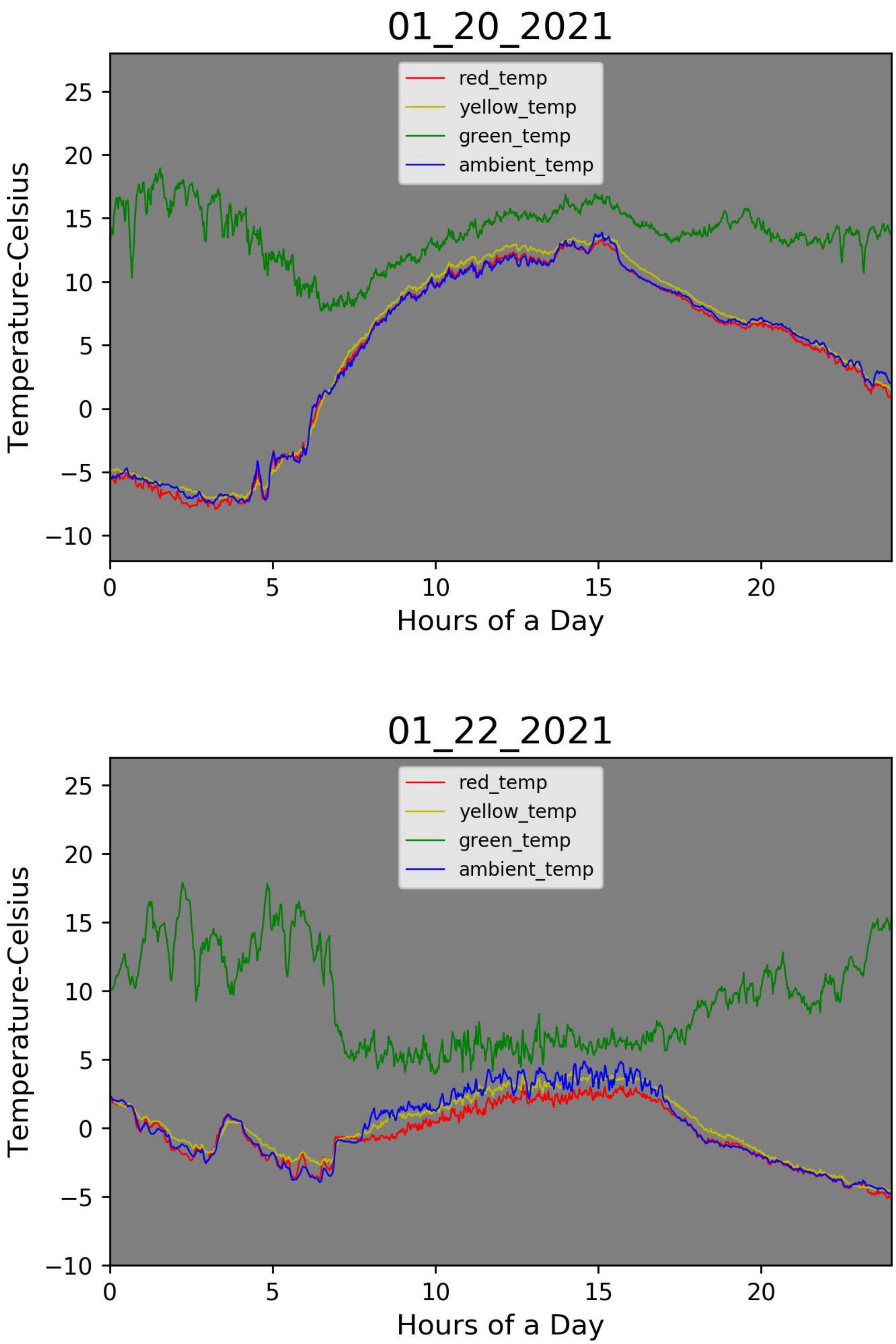
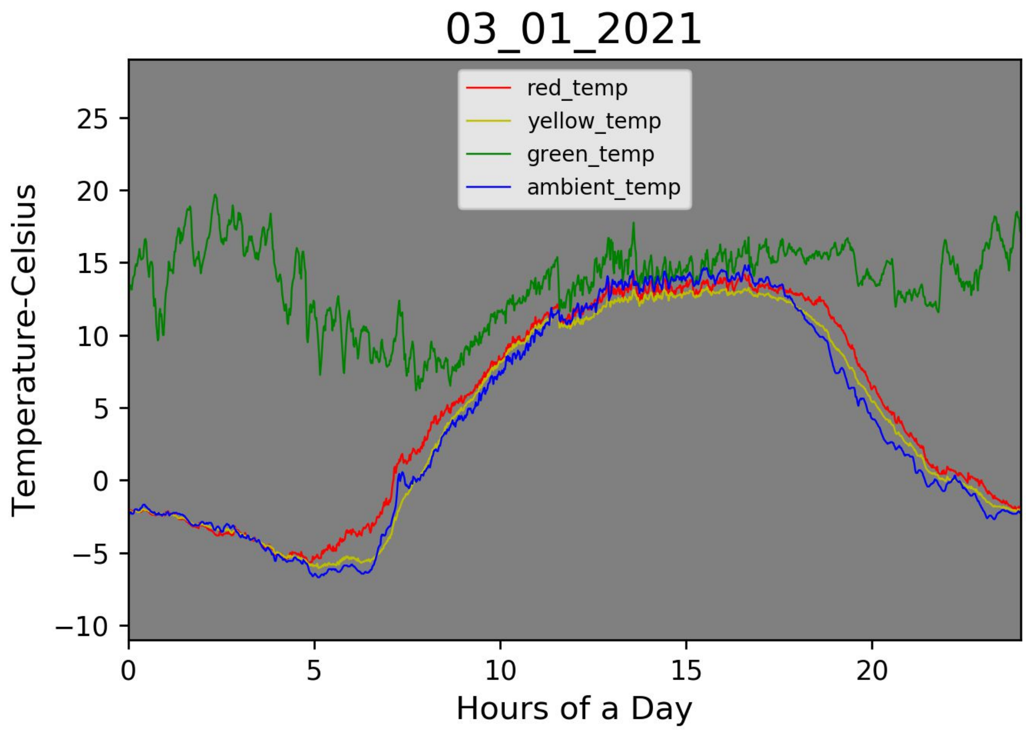


Figure 6 Lawrence field test data during the coldest days in January and February 2021, showing the performance of the red, yellow, and green signal lights under wintery weather conditions. We also fixed the loose mounting of temperature sensors. Such loose mounting explained the recorded lens' surface temperature drop of the red and yellow signal lights close to the ambient temperature in late January and early February.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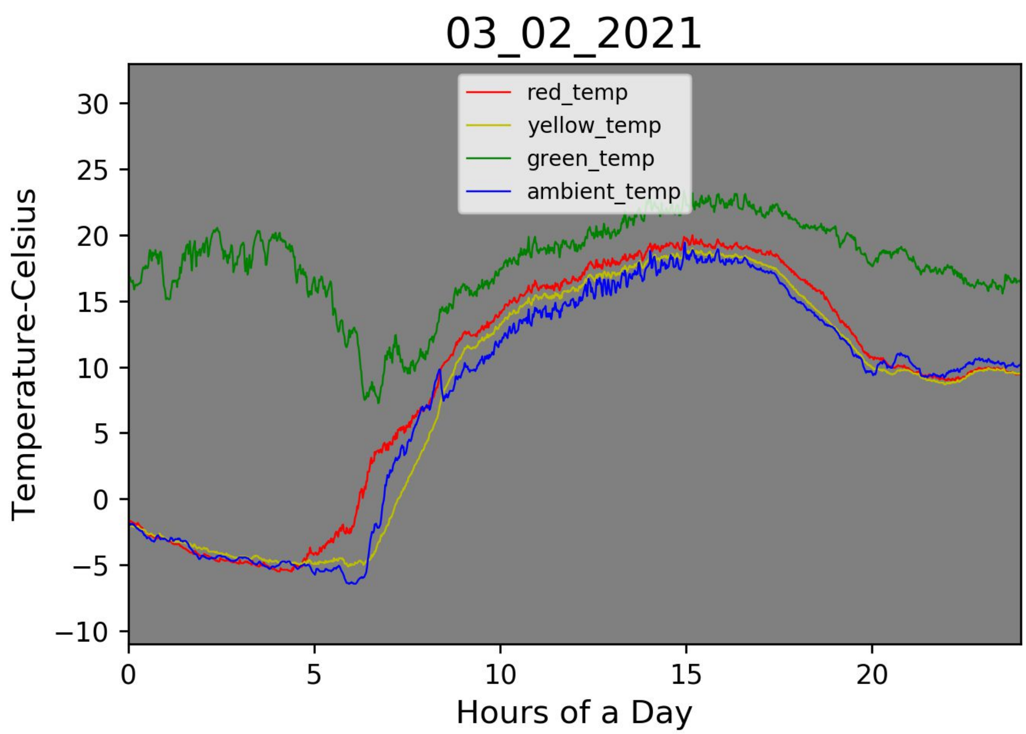
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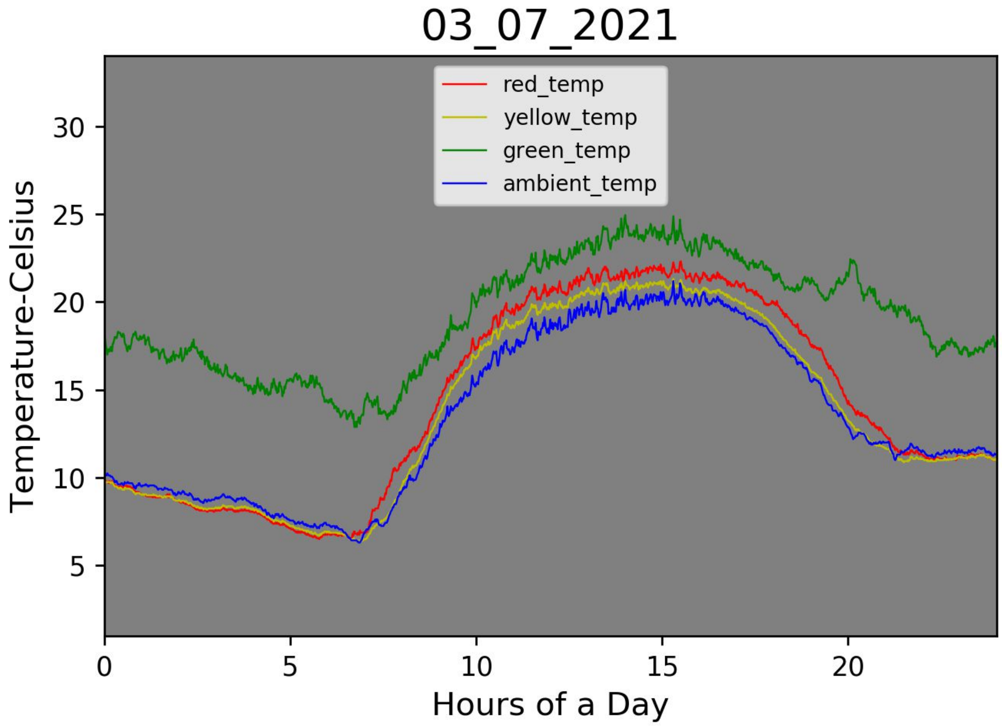
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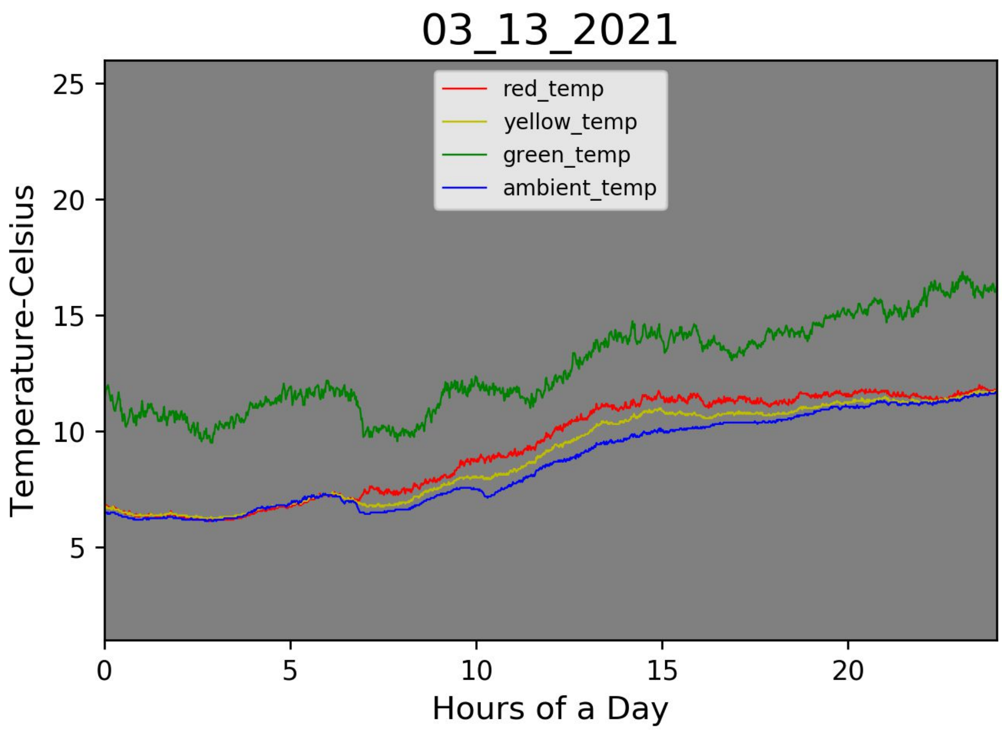
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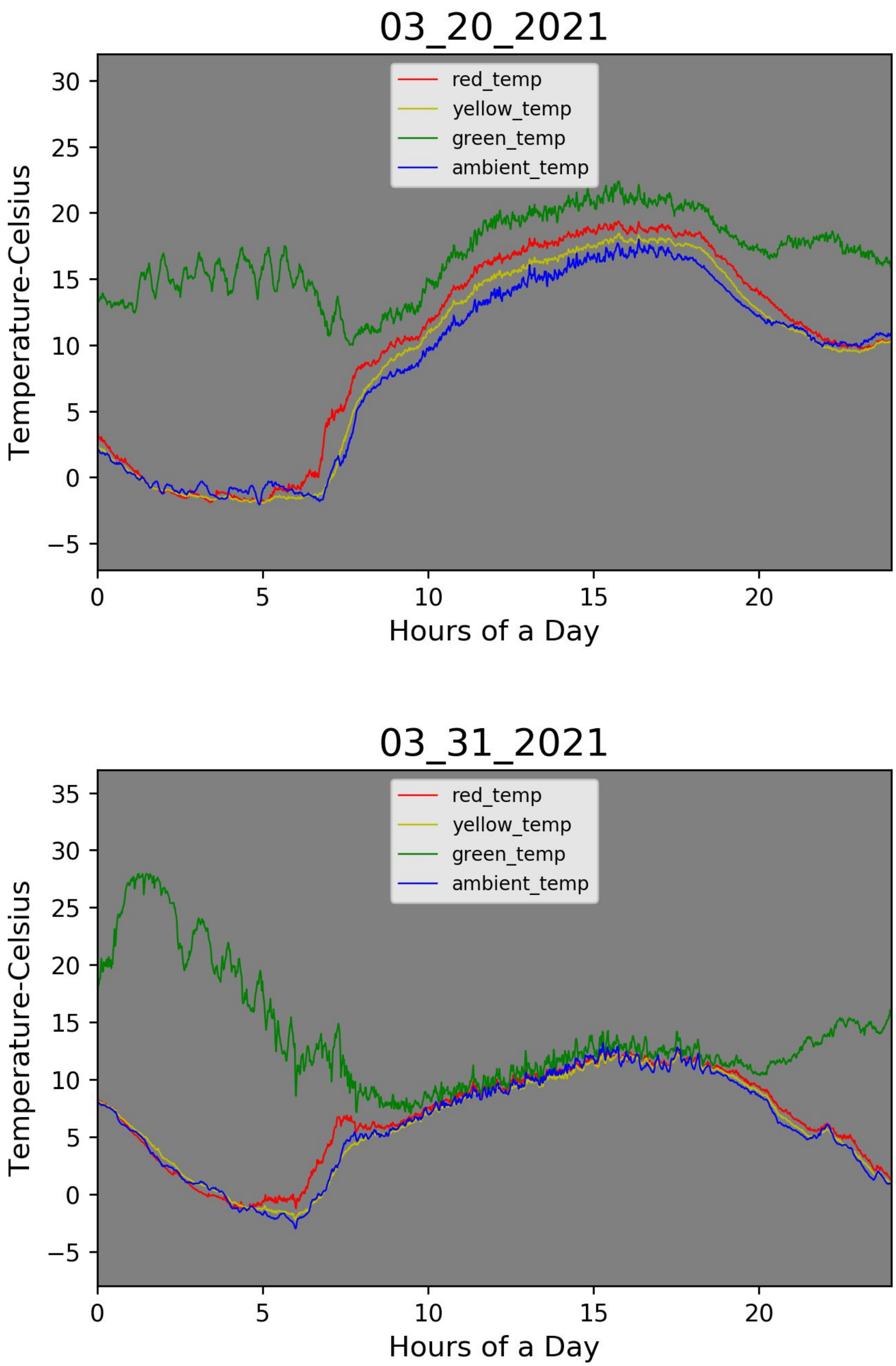

Figure 7 Lawrence field test data in March 2021 after the field visit on Feb 25th, showing the normal performance of the red, yellow, and green signal lights under spring weather conditions, especially for the green signal light which has the longest power on time. The ambient temperature now is slightly lower than the yellow and red signal lens with very short signal on time, because the ambient temperature sensor is mounted inside a shade, which isolates the sensor from the wind.

Anticipated work next quarter:

Starting from April 1, 2021 till June 30, 2021, we are planning to conduct the following tasks.

1. Assemble the finalized 5^{th} generation of prototypes with the corrected fresnel lens disc samples, for field tests in Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland.

2. Complete writing the manual to be used by signal crews of different states for mounting the new self-de-icing signals and the corresponding data recording and remote monitoring system, for the upcoming field test site use.

3. Continue to work with Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland to find the other 4 field test sites and the detailed plan on field installations.

4. Start new field test installation in the summer, sometimes in between June and July.

Significant Results:

As of Dec 31, 2020, 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.

- Talked with the fresnel lens company to modify the design and form factor of the currently adopted 96 individual lenses mounted in the housing to a whole piece of disc embedded with a total of 96 fresnel lenses on it.

- The field monitoring system has added mobile communication information device with data plan to remotely send the data of the signal performance back to the laboratory on daily basis for real-time performance monitoring, which is under testing on the roof.

- The problem of defective signal light housing with concave lens surface made during the production process has been solved with improved molding technology. A total of 100 new samples are made of Markrolon 2807 and tested with a maximum tolerance of 1.5 mm for mass production.

- A new fresnel disc with 96 small fresnel lenses integrated on it has been designed with the desired improvements, and is currently being custom-made in a factory through injection mold.

- We have installed the new remote monitoring system with mobile communication in the Lawrence test site, in addition to the original reliable "local" data monitoring system that kept running in the past year.

- The self-de-icing signals have survived both winter and summer functioning as expected, without any signs of snow and ice accumulation on the signal lens in cold winter, and abnormal performance in hot summer.

- Corrections have been made in the injection mold for making the new fresnel disc with 96 small fresnel lenses integrated on it.

- Writing a manual to be used by signal crews of different states for mounting the new self-de-icing signals and the corresponding data recording and remote monitoring system, for the upcoming field test site use.

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.