# Design of Lighting Data Platform for Realization of Natural Light Reproducing Lighting


Seung-Taek Oh
Smart Natural Space Research Center
Kongju National University
Cheonan, Republic of Korea
ost73@kongju.ac.kr(ORCID: 0000-0003-1512-9897)

Yang-Soo Kim
Dept. of Computer Science & Engineering
Kongju National University
Cheonan, Republic of Korea
kys@kongju.ac.kr

Jae-Hyun Lim*
Dept. of Computer Science & Engineering
Kongju National University
Cheonan, Republic of Korea
defacto@kongju.ac.kr(ORCID: 0000-0001-7169-8969)



***Abstract*—** Lighting technology continues to evolve to provide more beneficial light to humans. Efforts are continued to provide natural light properties that are recognized as the most beneficial to humans, and lighting with subdivided functions such as health, emotion, efficiency, and energy based on natural light properties is being developed. Nonetheless, there is almost no long-term measurement of natural light data for more than one year, which is essential for research and development of natural lighting. Most of them use short-term natural light data of less than one month, and there is no clear standard and basis for natural light properties data. Therefore, in this study, we propose a standard for the data by measuring, acquiring, and analyzing natural light, and propose a natural lighting data platform that supports research and development of lighting by function. To build data, which is the core of the platform, 70 types of natural light properties data measured through high-end optical measurement equipment over 7 years were built as a big data DB. Filtering were performed for two times on the constructed DB. Based on the constructed DB, a simulation experiment was performed on health lighting that provided the daily color temperature cycle of natural light. The daily color temperature cycle of natural light could be reproduced within the average absolute error of 0.03%, and the application plan for the proposed platform in the field of natural light reproduction lighting technology was presented.



***Keywords— Natural Light, Lighting Data, Platform, Design of Lighting, Natural Light Reproducing***


## I. Introduction

Lighting technology is evolving to provide more beneficial light to humans, more than the traditional purpose of providing high-efficiency light [1]. As the effects of light properties such as illuminance, color temperature, and wavelength of artificial lighting on the human body are known [2], the use of LED lighting has been spread and the development of light properties control technology has been developed, efforts to provide a suitable light environment for each lighting use are continued [3]. Modern lighting continues to develop for realization of the goal of Human Centric Lighting (HCL) [4], and the attempts by many researchers continue to provide natural light properties through the artificial lighting that is recognized the most beneficial to humans [5].

In the light source field, a light source that realized wavelength properties similar to natural light has been released [6]. Whereas in the field of LED lighting, emotional lighting technology that provided the hues and color temperature of natural light was introduced by combining multiple light sources with different color temperatures and controlling each light source for each channel. In addition, a lighting control method that helped human health by realizing the change in color temperature in the daily cycle of natural light has been studied [7]. Some of the lighting manufacturers launched the lighting products that calculated the changing cycle of color temperature of natural light as per each location (latitude, longitude) and a health lighting technology that provided the color temperature of natural light on a relatively clear day to the room in real time was proposed. Also, energy-saving lighting technology that linked and controlled the brightness of indoor lighting in response to changes in illuminance of natural light was also introduced.

As has discussed above, the subdivided natural light-based lighting technologies for each function have been studied and developed, and more realistic natural light properties are being pursued. However, natural light-based lighting technology can be realized through analysis based on measured natural light data accumulated over a long period of time. The research and development cases which have been introduced until now have a limitation in that they provide only some of the properties of natural light acquired through short-term measurement. In addition, there was no case that presented a clear standard and basis for which natural light properties data was applied to the lighting technology, and research in the related field is lacking.

Therefore, this study proposes a natural lighting data platform that supports research and development of the lighting for each function based on natural light properties by proposing a standard of natural light properties through measuring, acquiring, and analyzing natural light. Figure 1 is the overview of the proposed platform. After building a natural light big data DB based on 70 types of natural light properties acquired through long-term (7 years) actual measurement, the control standards for natural light properties necessary for research and development of lighting for each function were provided through analysis. It was, therefore intended to support the realization of natural light reproduction lighting.

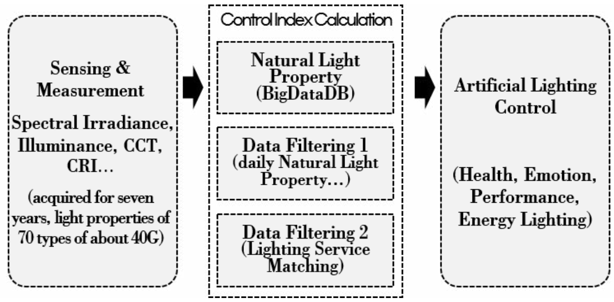



Fig. 1. Overview of the natural lighting data flatform

## II. Natural Lighting Data Platform

Figure 2 shows the structure of the natural lighting data platform proposed in this paper-a data acquisition unit that measured and acquired light properties from the lighting environment, a natural light big data DB that stored the acquired light properties data, and a data process unit that supported the lighting service by calculating and providing control indices of natural light through natural light bigdata DB-based analysis.

### *A. Data Acquisition (Sensing and acquisition of natural light properties)*

The data acquisition unit accurately and precisely measured and acquired the properties of natural light that changed every moment to build a natural lighting data platform. The spectral power distribution in the 200 - 800nm wavelength band of natural light, tristimulus values (X, Y, and Z), Illuminance, Correlated Color Temperature (CCT), and CRI were measured and acquired using a spectrometer. In addition, additional measurement and acquisition of optical properties such as illuminance, color temperature, chromaticity coordinates, and luminance were possible through color sensors and luminous sensors. Also, for artificial light (multi-channel LED lighting), the light properties by control index for each channel and the amount of lighting energy consumption by lighting control were measured. For this purpose, a power sensor was applied. In addition, a fine dust sensor and an image sensor were installed to collect atmospheric environment, location (latitude, longitude), and sun-related information (sky image, sunrise and

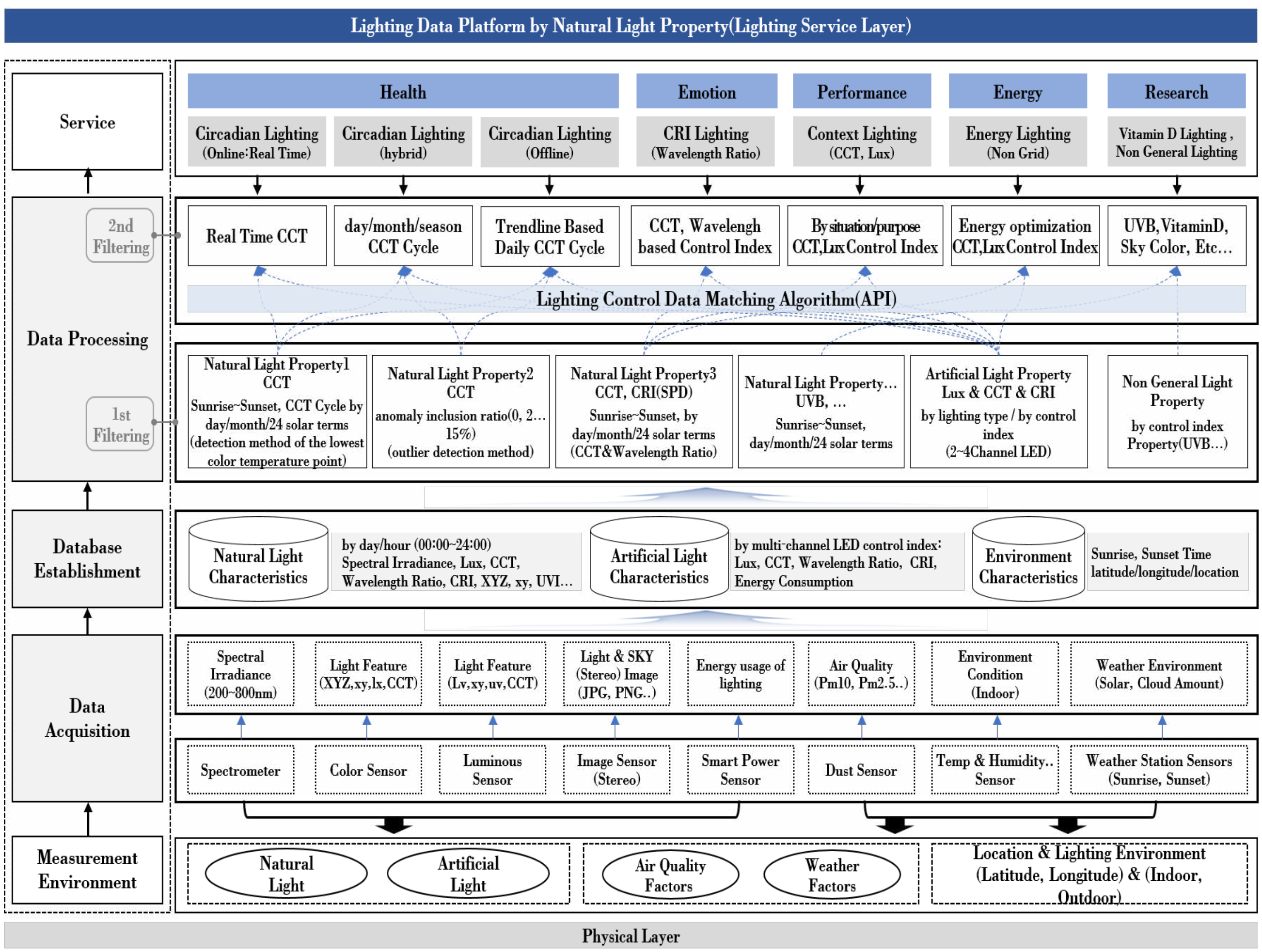



Fig. 2. Natural lighting data flatform

sunset times, elevation angle, and azimuth) that could affect natural light illumination were also acquired.

In this study, natural light was measured all the time by applying a spectrometer (CAS 140CT, Instruments, Germany) to construct the proposed platform. When operating the spectrometer, the Auto Integration Time function, which automatically adjusted the amount of light collected in response to large changes in solar illuminance was applied. Furthermore, a solar tracker that tracked the altitude and azimuth of the sun was fabricated and applied so that accurate natural light properties could be acquired in response to changes in the position of the sun over time.

Table 1 shows the equipment detail of the natural light measurement. Figure 3 shows the measured natural light properties along with the examples of the SpectralRaw data by time.

TABLE I. MEASUREMENT OF NATURAL LIGHT

| Category | Measurement condition and method |
|---|---|
| Measured date | 1 Jan. 2015 to present (longer than 7 years) |
| Equipment | Spectroradiometer (CAS-140CT, Instruments) |
| Location | Rooftop of K University building<br>(latitude: 36.8505471, longitude: 127.1528341) |
| Measurement cycle | 00:00 - 24:00, except rainy days |

Figure 3 shows the example of the measurement of natural light properties by day (28 Jan. 2022). The illuminance on that day was 0-115,000 Lux and the color temperature was about 3,300~5,500K. The Spectral RawData of the sunlight differed by time.

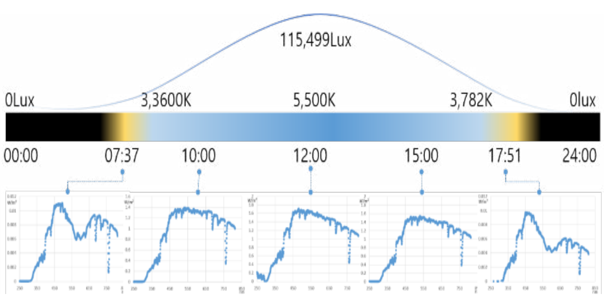
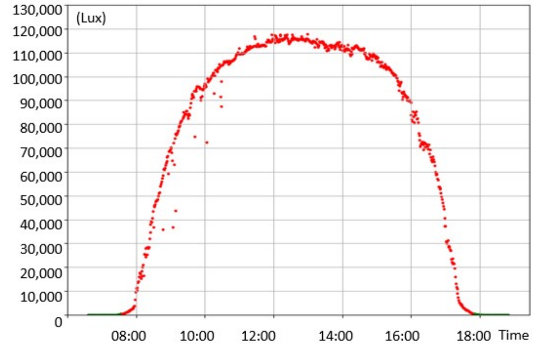


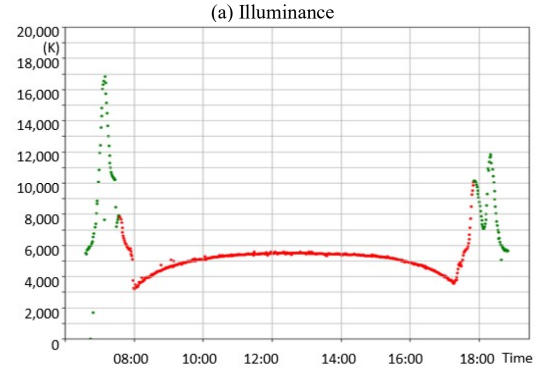

Fig. 3. Examples of the measured natural light properties (28 Jan. 2022)

## B. *Database Establishment (DB of natural light big data)*

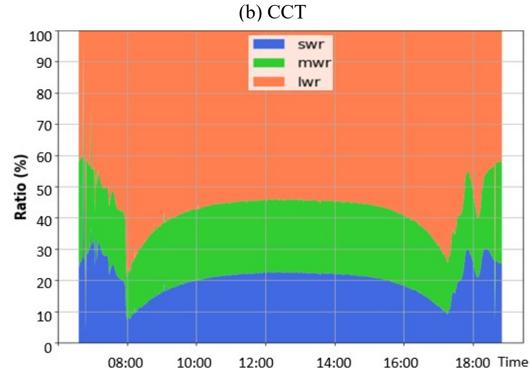
The properties of natural light measured at all times were stored and managed through the natural light big data DB based on MySQL and Mongo DB. The natural light properties were stored in a daily record format, and it was composed of optical properties such as illuminance, color temperature, ratio of short- medium-long wavelength band and chromaticity coordinates x and y calculated and derived based on the spectral properties as shown in Figure 4.



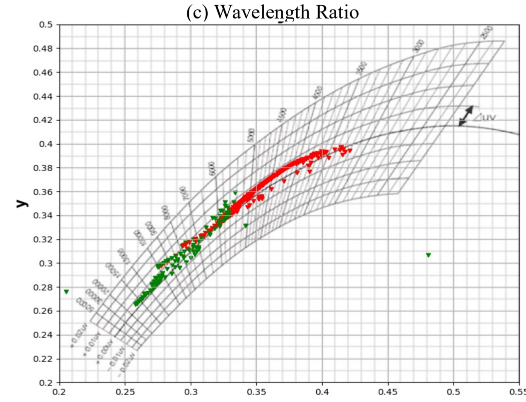

(a) Illuminance




(b) CCT




(c) Wavelength Ratio




(d) Chromaticity Coordinates

Fig. 4. Natural light properties (28 Jan. 2022)

Figure 4 is the visualized daily natural light properties for each optical property. As shown in Figure 4, natural light properties for every minute of each day were acquired, calculated, and organized as shown in Table 2.

TABLE II. RESULT OF EXTRACTION OF NATURAL LIGHT PROPERTIES BY DAY

| Relative Time | Unit | … | SunRise +30 | … | Noon | … | SunSet -30 | … |
|---|---|---|---|---|---|---|---|---|
| Absolute Time | | … | 08:06 | … | 12:00 | … | 17:21 | … |
| Illuminance | Lux | … | 17,604 | … | 115,499 | … | 8,979 | … |
| CCT | K | … | 3,361 | … | 5,506 | … | 3,977 | … |
| SWR | % | … | 7.7 | … | 22.5 | … | 12.0 | … |
| MWR | % | … | 15.3 | … | 23.3 | … | 17.6 | … |
| LWR | % | … | 76.9 | … | 54.2 | … | 70.5 | … |
| CRI | - | … | - | … | - | … | - | … |
| x, y, … | … | … | … | … | … | … | … | … |

As a daily natural light property, the spectral irradiance (Raw Data) for each time-period shown at the bottom of Figure 2 was stored together. In addition, the ratio of the short-medium-long wavelength band calculated through spectral irradiance analysis and the calculation results such as illuminance, color temperature, and CRI were composed. After measuring and analyzing the natural light properties for more than 7 years, a natural light big data DB consisted of 70 types of light properties data of more than 40G was constructed. In addition, the optical properties according to the control of the input current for each channel of artificial lighting (multi-channel LED lighting) for realization of natural light properties were also acquired. The optical properties of artificial lighting were set as the control indices of illuminance, color temperature, wavelength ratio, CRI, and energy consumption, and were measured in a lighting box that blocked external light. The optical properties of artificial lighting can be managed together through the proposed platform if a lighting company provides it in the same format in the future.

### *C. Data Processing (Extraction of natual light lighting data)*

Data processing performs the function of extracting natural light lighting data for each function required by the user, and this process passes through a two-stage filter process. Primary filtering is a step of extracting reference optical properties for natural light reproduction. Since the previous natural lighting technology independently drew control standards for natural light properties without a separate standard or basis, so this study was intended to present a standard for extracting natural light properties to improve old practice.

To classify natural light properties and extract data, it is necessary to understand the degree of clear and cloudy day for each day, and it is also necessary to determine the start and end of the color temperature cycle. In the past, most of the forecasts depended on information provided by the Korea Meteorological Administration, such as cloudiness, to determine the clear or cloudy in the area. On the contrary, in the proposed method, an outlier ratio of color temperature was applied. In addition, in the case of natural light, it is very difficult to specify the daily color temperature cycle zone due to the constantly changing weather and the high illuminance and color temperature change at sunrise and sunset. In the preceding studies, the color temperature cycle was realized in their own way. In this study, the color temperature cycle zone for each day was specified by applying a search method for lowest point of color temperature near sunrise and sunset. By applying these methods, the reference natural light properties necessary to implement natural lighting for each function were derived. Natural light properties for each day were classified by outlier inclusion ratio, and after searching for the lowest point of color temperature after sunrise and before sunset, primary filtering was performed to extract color temperature, wavelength ratio, and CRI for each hour of day/month/season. Table 3 shows the part of the color temperature table for each day/month/season for each day/month/season as an example of the outcome by performing the primary filtering.

In the primary filtering, tables for illuminance, color temperature, CRI, and power consumption by control index for each type of artificial lighting (2 to 4 channels, for general, home, office etc.) were composed together. In addition, special lighting such as vitamin D synthesis lighting and artificial window lighting and optical properties information for research purpose lighting could be additionally configured.

TABLE III. EXTRACTED RESULTS OF DAILY NATUAL LIGHT PROPERTIES (UNIT:CCT)

| Category | 2018.02.08 | 2019.02.21 | 2019.03.08 | ~ | 2017.12.27 | 2018.01.06 | 2019.01.26 |
|---|---|---|---|---|---|---|---|
| | Advent of spring | Rain water | Stirring of insects | ~ | Winter solstice | Lesser cold | Great cold |
| ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 9:00 | 4101.11 | 4533.72 | 4988.84 | ~ | 4406.77 | 4185.38 | 4280.12 |
| 9:01 | 4112.11 | 4549.73 | 5001.83 | ~ | 4418.56 | 4197.52 | 4295.43 |
| 9:02 | 4125.08 | 4555.03 | 5017.35 | ~ | 4419.06 | 4209.81 | 4311.4 |
| 9:03 | 4133.13 | 4569.93 | 5019.89 | ~ | 4427.98 | 4224.19 | 4322.98 |
| 9:04 | 4142.38 | 4581.3 | 5020.13 | ~ | 4433.37 | 4238.03 | 4340.79 |
| 9:05 | 4155.17 | 4590.89 | 5018.71 | ~ | 4440.23 | 4246.66 | 4359.84 |
| 9:06 | 4164.6 | 4597.96 | 5027.44 | ~ | 4451.22 | 4259.41 | 4377.96 |
| 9:07 | 4172.05 | 4601.91 | 5030.39 | ~ | 4457.28 | - | 4387.45 |
| 9:08 | 4183.61 | 4604.07 | - | ~ | 4464.74 | 4272.32 | 4399.3 |
| 9:09 | 4194.67 | 4612.76 | 5033.79 | ~ | 4474.07 | 4288.67 | 4411.54 |
| 9:10 | 4204.54 | 4608.1 | 5038.56 | ~ | 4479.65 | 4300.43 | 4424.19 |
| 9:11 | 4217.56 | 4612.11 | 5050.92 | ~ | 4490.54 | 4313.2 | 4431.66 |
| 9:12 | 4227.25 | 4615.01 | 5051.85 | ~ | 4499.62 | 4321.77 | 4445.2 |
| ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |

Secondary filtering among the data processing steps is a step of providing control indicators for lighting control requested by the user in natural light properties for the results of primary filtering as in Table 3. Users can request control indicators for the realization of natural light lighting by various functions such as health, emotion, efficiency, energy, and research through the proposed platform. Health lighting was made to request a color temperature cycle by day/month/season, real-time color temperature, and a standalone-type color temperature control cycle that excluded server intervention. When a daily color temperature cycle was requested, the color temperature for each hour was extracted from the standard natural light properties, which was the primary filtering result, and then a separate optical properties table was constructed and provided to the user. At this time, when the user's light properties for artificial lighting fell under the primary filtering result, the control index for lighting was to be transmitted together. For emotional lighting, brightness, and color temperature for each purpose of lighting were provided, and a color temperature control index was derived and provided in consideration of CRI of natural light. In addition, efficient lighting was designed to provide illuminance and color temperature suitable for the user's context. In this case, a function of recognizing the light of the user's surrounding environment and adaptively providing lighting for each purpose of use was included. In addition, energy lighting control standards were derived and provided to save energy by providing only the required illuminance for each indoor area based on natural light. For research purpose lighting, natural light properties were calculated and provided for realization of special-purpose lighting technology such as vitamin D reinforcement.

The natural lighting data platform generated standard through primary filtering to extract natural light properties, and calculated optical properties such as color temperature cycle, CRI, and spectral properties for research and development of natural light lighting by function through secondary filtering. Afterwards, it was built to support the realization of lighting technology based on natural light properties by delivering the calculation results of control indicators to users through API.

## III. Experiment And Analysis

To reaffirm the operability of the proposed platform, a simulation experiment was performed on a health lighting service that provided a daily natural light color temperature cycle. In response to the user's request, the proposed platform searched the natural light classification table based on the outlier ratio, which was the primary filtering result, and selected a specific day having an outlier ratio within 5% (or 2-15%). After that, the color temperature cycle for health lighting service was extracted from the light properties on the selected date (28 Jan. 2022) from the standard light properties table, which was the result of the primary filtering. In addition, after checking the user's artificial lighting (4CH LED) information, natural light properties were reconstructed to reproduce the daily color temperature cycle of natural light and provided to the user. Table 4 and Figure 5 shows the extraction results of natural lighting data.

TABLE IV. Extracted Natural Lighting Data

| **Category** | **Extraction of lighting data based on natural light properties** | | | | |
|---|---|---|---|---|---|
| **Time** | **Natural Light Property CCT(K)** | **Artificial Light Property (Control Index)** | | | |
| | | **1CH(K) (5,000)** | **2CH(K) (2,700)** | **3CH(K) (6,500)** | **4CH(K) (4,000)** |
| 08:00 | 3,205 | 16 | 112 | 0 | 112 |
| 09:00 | 4,170 | 0 | 16 | 64 | 160 |
| … | … | … | … | … | … |
| 12:00 | 5,506 | 96 | 0 | 128 | 16 |
| 12:30 | 5,481 | 112 | 0 | 128 | 16 |
| … | … | … | … | … | … |
| 17:00 | 3,988 | 0 | 48 | 64 | 128 |
| ~ | ~ | ~ | ~ | ~ | ~ |

As shown in Table 4, the lowest color temperature near sunrise (07:30) and sunset (17:51) on the test starting day were searched and the color temperature was adjusted to 30 minutes after sunrise (08:00) and 50 minutes before sunset (17:00) to derive daily color temperature cycle. Figure 5 shows the result of performing user lighting service by applying the derived natural lighting data. This is the result of extracting and applying the control index to reproduce the natural light color temperature by time by referring to the optical properties table for K company's 4-channel LED lighting.

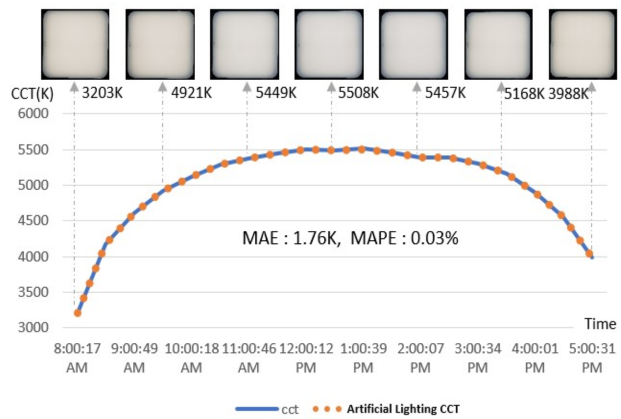



Fig. 5. Results of the lighting service to the users

As shown in Figure 5, health lighting service was provided to users by extracting the daily color temperature cycle through the natural light lighting data platform. As a result, the color temperature of natural light and artificial light showed a difference of 1.76K in mean absolute error (MAE) and 0.03% in mean absolute error (MAPE), confirming that a reliable daily color temperature cycle could be derived and provided through the primary and secondary filtering in the proposed platform.

## IV. Conclusion

Recently, many lighting technologies and studies that simulate the properties of natural light have been introduced, but there has been no case of suggesting the basis or standards for the properties of natural light as a reference. In this study, the standard of natural light properties data necessary for the realization of natural lighting was presented, and a natural lighting data platform that provided the standard was proposed. The proposed platform consisted of a natural light properties data acquisition unit, a natural light big data DB that stored it, and a data processing unit that extracted control standards for natural light lighting through analysis. First, the data acquisition unit built a natural light big data DB based on the natural light properties of about 70 types and 40G capacity acquired through actual measurements for about 7 years by measuring with equipment such as spectroradiometer. After that, the data processing unit performed natural light big data DB-based analysis. The data processing unit constructed a natural light properties table by extracting color temperature, CRI, and spectral properties by day/month/24 solar terms through primary filtering. In the primary filtering, a natural light properties table for each color temperature outlier ratio was additionally configured to determine the degree of clear and cloudy for each day. Also, to compose the natural light properties table, daily color temperature cycle zone was set using detection method for the lowest point of color temperature. After that, in the secondary filtering, control indices of natural light properties necessary for realization of lighting technology by function such as color temperature cycle and CCT/wavelength-based properties by day/month/24 solar terms were derived and provided. Through this, the method of acquiring and analyzing the measured natural light properties and the standard of natural light data for the realization of natural lighting by function were presented. In addition, a platform-based method for sharing and utilizing data based on natural light properties was presented. In subsequent simulation experiments, it was confirmed that natural light lighting based on the proposed platform could be realized by reproducing the color temperature cycle of natural light within an average absolute error of 0.03%.

In the future, we plan to conduct additional research for the implementation of the proposed natural lighting data platform. Furthermore, we will continue to put efforts to create various natural lighting services based on the proposed platform.

## ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (2019R1A6A1A03032988). This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(2020R1I1A3073320). This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(RS-2023-00245425).

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