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**Article**

# An experimental study on the effects of lighting in the offices

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## ABSTRACT

In recent years, the number of studies on light and its effects on human beings has increased significantly. Various studies have shown that light has non-visual as well as visual effects on humans, and that these effects direct physiological, psychological, and behavioral responses such as alertness and circadian rhythms. The relevant literature cites national/international standards, legislation, metric/numerical measurement methods, and some suggested calculation methods (Circadian Stimulus, Equivalent Melanopic Lux, etc.) to quantify these effects. However, the data on the measuring instruments used and the measurement methods followed in indoor/in situ studies are quite limited. In order to contribute to the subject, research has been initiated to determine the visual and non-visual effects of light on indoor working environment users. This research presents and compares the results of an experimental study carried out to compare the photometric and radiometric measurement results of the same parameters (Ev, EML, *Tcp* values) by two different devices. To this end, measurements were taken in two different office environments with different daylight proportions to assess whether and under which conditions the devices could be used as substitutes for one another. In order to achieve this, hypothesis tests were applied to the test results to estimate the probability of the two measurements being equal.

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## INTRODUCTION

All living things have the instinct to organize their internal cycle according to the characteristics of external stimuli. This instinct, which begins in humans in the womb, is the most fundamental determinant of human-built environment interaction (McKenna & Reiss, 2018). When the subject is considered from this point of view, especially the spaces in which people live/work for a long time, direct the attention, emotions, and behaviors of their users with different features such as function, size, lighting, etc., and play an active role in the change of their existing biological/circadian rhythms.

In the literature, the effects of light on human beings are considered in two groups: visual and non-visual effects. The visual effects of light are evaluated through luminometric parameters (illuminance level, luminous flux, luminous intensity, luminance, color properties of light) related to the lighting conditions in the physical environment. The values given in the standards for these quantities are basically related to the "photosensitivity *V(λ)*" properties of cone light receptors, especially M/green cones, in the retina, which operate under "photopic vision" conditions.

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Non-visual effects of light affect human physiological and neurobehavioral brain functions, especially cognitive tasks including basic functions such as perception, attention, memory, language problem solving, reasoning, decision making, psychomotor, and executive functions. Non-visual effects of light are of two types: short-term/instantaneous and long-term effects. Short-term/instantaneous effects in the body can be exemplified by the pupil dilation response and suppression of melatonin hormone secreted by the pineal gland. Long-term effects cause physiological and psychological disturbances such as sleep/wake (circadian rhythm), heart, digestive system disorders, winter depression, etc. (International Commission on Illumination, 2018).

In the evaluation of the non-visual effects of light, parameters related to "melanopic vision" conditions, which also govern the biological/circadian rhythm of humans, are taken into account. These are linked to light exposure duration (minutes), time of day (morning, noon, afternoon, evening, night, etc.), user characteristics (age, gender, education, etc.), and user's light history (living conditions), in addition to luminometric parameters, although these are not yet finalized today (Khademagha et al., 2016).

However, there are numerical models in the literature to explain the relationship between non-visual effects and light measurement parameters. The first example is the "Circadian Action Factor (CAF)" model derived from the experimental studies of Gall (Gall & Bieske, 2004), Brainard (Brainard et al., 2001), and Thapan (Thapan et al., 2001) in the early 2000s. This model correlated the changes in melatonin suppression depending on the wavelengths of light with various luminometric magnitudes. The model suggests different CAF values depending on the time of day; for example, high CAF values during the day and low CAF values at night are more favorable (Oh et al., 2014).

In 2012, at Rensselaer Polytechnic Institute (Lighting Research and Technology, LRC) in the USA, Rea et al., (2012), developed the "Circadian Stimulus (CS)" model. In the Circadian Stimulus model, the "Circadian Light (CLa)" unit is used. In the CS model, a rating is introduced for the rate at which the amount of light entering the eye suppresses melatonin production after 1 hour of exposure to light. In this model, for example, a Circadian Stimulus (CS) of 0 indicates that melatonin is not suppressed, while a CS of 0.7 indicates a theoretical 70% suppression of melatonin. The CS also includes values that should be achieved for at least 1 hour of light exposure. For example, for a typical office environment, CS ≥0.3 during the daytime, CS ≤0.2 in the afternoon, and CS ≤0.1 in the evening and at night (Rea et al., 2010; Rea et al., 2012). With the CS toolbox developed by LRC between 2017 and 2020, CS and CLa values can be calculated for the lighting environment in which users are located (Figueiro et al., 2016; Lighting Research Center, 2020).

In 2014, Lucas et al. (2014) developed a model for the effects of light called "Equivalent Melanopic Lux (EML)." This model assumes that there are five light-sensitive receptors in the retina: S-cone, M-cone, L-cone, rod, and ipRGC (intrinsically photosensitive retinal ganglion cell). The intrinsical photosensitivity of retinal ganglion cells (ipRGC) is mediated by the melanopsin photopigment they contain. It is recommended that the EML value at eye level should be at least 200 EML between 09:00-13:00 during the day and at most 50 EML at night (Lucas et al., 2014).

In 2014, the International Well Building Institute (IWBI) developed a certification system (Well Standard, WS) to assess the minimum requirements for circadian rhythm. This certification system is based on the EML model previously defined in the literature. In the WS, the EML value is obtained by multiplying the illuminance level measured at eye level by a coefficient weighted according to the spectral energy distribution of the light illuminating the environment. Within the scope of WS, an EML rating has been introduced for the spectral distribution of light in indoor workspaces in non-residential building typologies (Lucas et al., 2014; International WELL Building Institute, 2021).

In 2018, the CIE published a standard for non-visual effects of light on humans via intrinsically photosensitive retinal ganglion cells (ipRGCs) that contain melanopsin. The International Standard CIE S 026/E: 2018 specifies a system for measuring optical radiation for ipRGC-influenced responses to light. The standard defines spectral sensitivity functions, quantities, and measurements to identify five types of photoreceptors that may contribute to the retina-mediated non-visual effects of light in humans, and the ability to stimulate each of them (European Committee for Standardization, 2017; International Commission on Illumination, 2018; International Commission on Illumination, 2019). In addition, the CIE has developed a toolbox to enable calculations and conversions of quantities related to ipRGC-influenced responses to light, implementing CIE S026 (International Commission on Illumination, 2020). The α-opic Toolbox calculates the spectral power distribution of the light the person is exposed to in $W/m^2$ by converting the spectral power distribution of the light into individual α-opic power level values for each of the five receptors in the eye.

In the literature, there are publications stating that the magnitude of the non-visual effects of light is related to the "spectral distribution of light." In these publications, it is stated that there are radiometric and photometric parameters related to the spectral distribution of light (Khademagha et al., 2018). In studies on the non-visual effect by taking into account the spectral distribution of light, in addition to measuring instruments such as lux meter, luminance meter, chroma meter, etc., which are generally used to determine the visual effects of light, a "spectroradiometer" is also used, which shows the spectral distribution of light in terms of spectral radiance level. These measuring instruments naturally have differences in the way they work. These distinctions can affect the results in terms of measurement accuracy and comparability and are therefore of great importance for design, research, and improvement studies in the field of lighting. There is a limited number of studies in the literature that take into account the differences in the functioning of these measuring instruments.

As can be understood from the above explanations, there are different approaches, different definitions, different measurement parameters, different measurement-evaluation-grading methods for these parameters in the literature on non-visual effects of light. In order to contribute to this issue, the present research was planned and measurements were started to determine the visual and non-visual effects of light on the users of an indoor work environment (office) with integrated lighting (natural and electrical lighting together).

This research presents and compares the results of an experimental study carried out to compare the photometric and radiometric measurement results of the same parameters (Ev, EML, *T*cp values) by two different devices. To this end, measurements were taken in two different office environments with different daylight proportions to assess whether and under which conditions the devices could be used as substitutes for one another. In order to achieve this, hypothesis tests were applied to the test results to estimate the probability of the two measurements being equal. The methodology of the study, the preliminary results of the experiments, and the evaluation of the results are presented in the following sections.

## RESEARCH METHODOLOGY

The aim of the research is to measure the non-visual effects of light on office users with different devices having different measurement methods and to evaluate the results. In this context, the steps of the research methodology can be summarized as follows:

- Determination of the characteristics of the office spaces selected as the experimental environment.
- Determination of experimental measurement times.
- Determination of measuring instruments to be used in the experiments.
- Comparative evaluation of measurement results.

### Experimental Environment Features

The research was carried out in two separate spaces, which are named as Office 1 and Office 2.

**Experiment 1 (E1):** The office space (Office 1) where the first experiment was conducted is located on the second floor of a four-story office building in the Kurtköy neighborhood of the Kadıköy district of Istanbul, Turkey (40°55'14"N latitude, 29°19'3"E longitude). The office (width 8.60 m, length 9.90 m, height 3.78 m) has a floor area of 82 $m^2$, and windows are oriented southeast. The space is divided into two parts: a manager's room (14 $m^2$) and an open office with 9 desks. The two spaces are separated by glass partitions. The façade of the building has a glass curtain wall system with aluminum joinery and vertical solar control elements. The ratio of window area to window wall area (transparency ratio) is 100%, and there is no external obstruction near the building. Generally, matte materials are used in the space. According to the Munsell Color System, the walls' paint is a high-value, low-saturation yellowish-red (10YR, 9/1), the ceiling's paint is black (N2/0). The floor is covered with gray (N 6/0), matte plastic flooring (PVC) material. Table separators are matte, medium value, and high saturated purple-blue (10B 6/8). There are matte and translucent fabric vertical curtains inside of the windows. The dimension of the curtain parts is 122 mm, and color is yellow with high value and low saturation (2Y 8/4). The reflectance of the interior surfaces of the office was measured with a spectrophotometer (Konica Minolta CM-2600d) as ceiling ρ: 0.1, wall ρ: 0.9, floor ρ: 0.3, desk ρ: 0.8, curtain ρ: 0.7.

The electrical lighting system of the space consists of 14 luminaires. Each luminaire has a linear LED light source (36 W, 6500 K, 80 Ra).

The study was carried out at user location 1, which is located in the viewing direction parallel to the window. The site plan and exterior view of the office building are shown in Figure 1, the experimental floor plan and section in Figure 2, and the interior photographs in Figure 3.

**Experiment 2 (E2):** The office space where the second experiment was conducted is located on the fourth floor of a fifteen-story office building in the Sahrayıcedid neighborhood (40°98'14"N latitude, 29°19'3"E longitude), Kadıköy district, Istanbul. The space (width 13.25 m, length 13.75 m, height 3.25 m) is divided into two by glass separators. The open plan office (158 $m^2$) has a total of 33 desks, 25 in the first section and 8 in the second section of the room, windows are oriented east, north, and northeast. The façade of the building has an aluminum joinery glass curtain wall system. The transparency ratio of the façade, which uses film on the window glasses, is 53%, and the nearest external obstruction to the building is 20 meters away.

On the interior surfaces of the space, according to the Munsell Color System, the walls' paint is high-value, low-saturated yellowish-red (10YR, 9/1), the ceiling's paint is matte white (N8/0). The floor is covered with medium-dark


**Figure 1**. E1office building site plan and building exterior view.

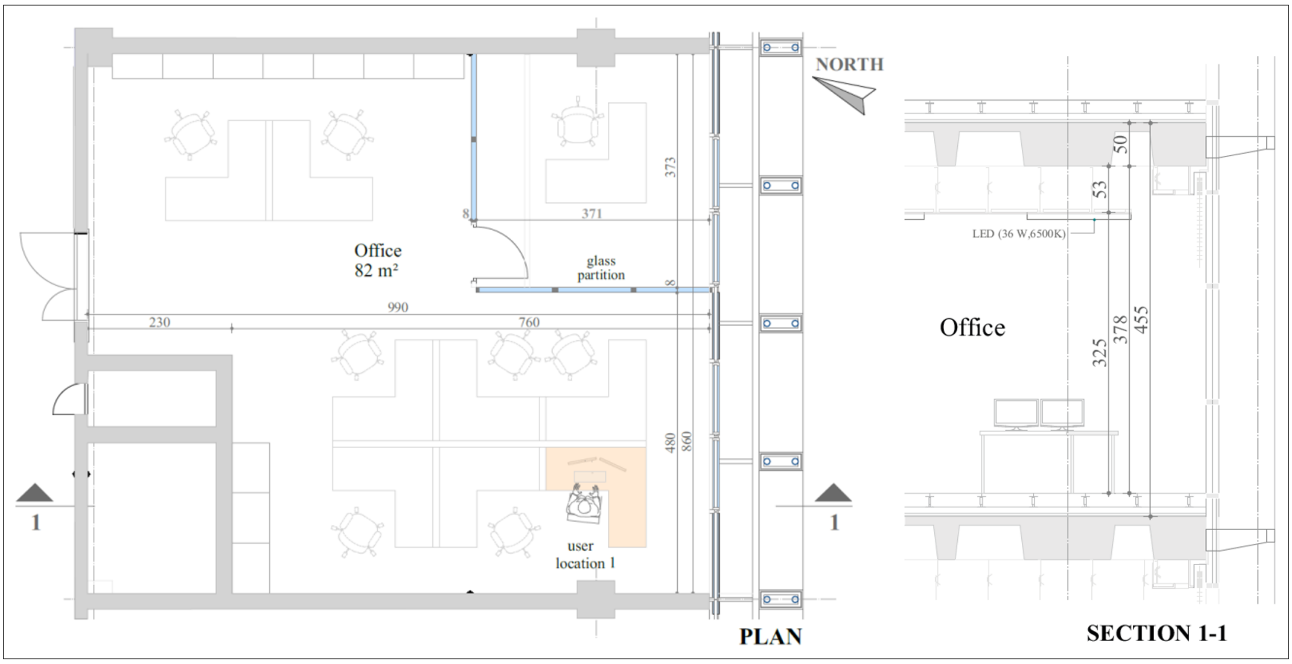


**Figure 2**. Plan and Section 1-1 of the E1office floor.

and saturated orange (7.5YR 6/6), mixed reflective laminate parquet flooring material. There are light yellow colored, opaque plastic vertical piece curtains (piece width, 90 mm) inside of the windows. The reflectance of the office interior surfaces was measured as ceiling ρ: 0.8, wall ρ: 0.7, floor ρ: 0.2, desk ρ: 0.8, and curtain ρ: 0.7. This study was carried out at user location 1, which is located in a north/northeast facing window.

The electrical lighting system of the space consists of 20 luminaires. Each luminaire is 0.60×0.60 m in size, with a diffuse lighting form. The LED light source (40 W, 3200 K, 80 Ra).

The site plan and exterior view of the office building are shown in Figure 4, the experimental floor plan and section in Figure 5, and the interior photographs in Figure 6.

**Measuring Times and Properties of Measuring Instruments**

The experiments were designed to investigate the non-visual effects of light on office users in two different situations, during the day and throughout the year. Light effects measurements were carried out:

- Three times during working hours, between 08:00 and 17:00 hours, to investigate the daily (diurnal) variation,

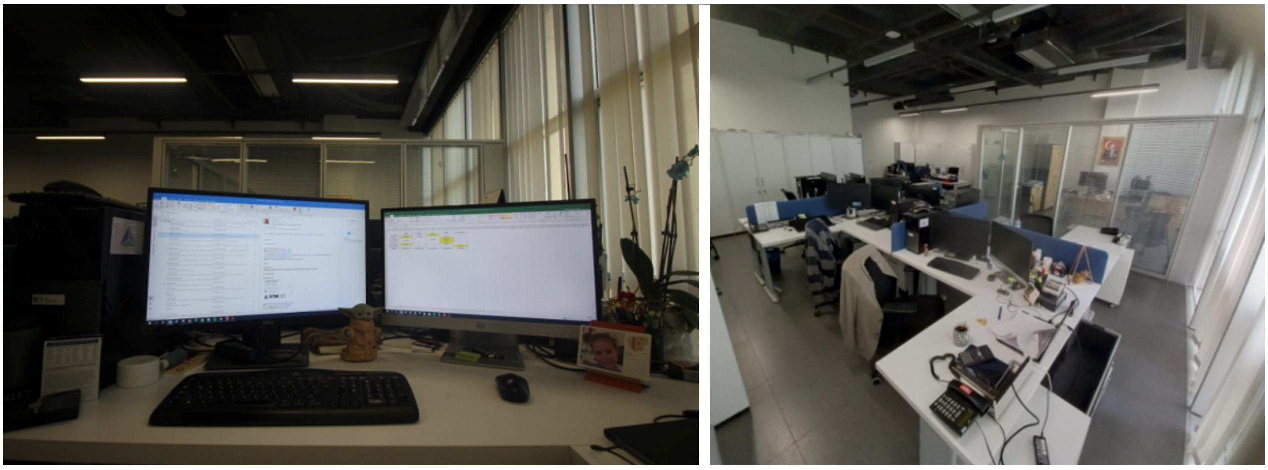

**Figure 3**. Interior view of E1 office.

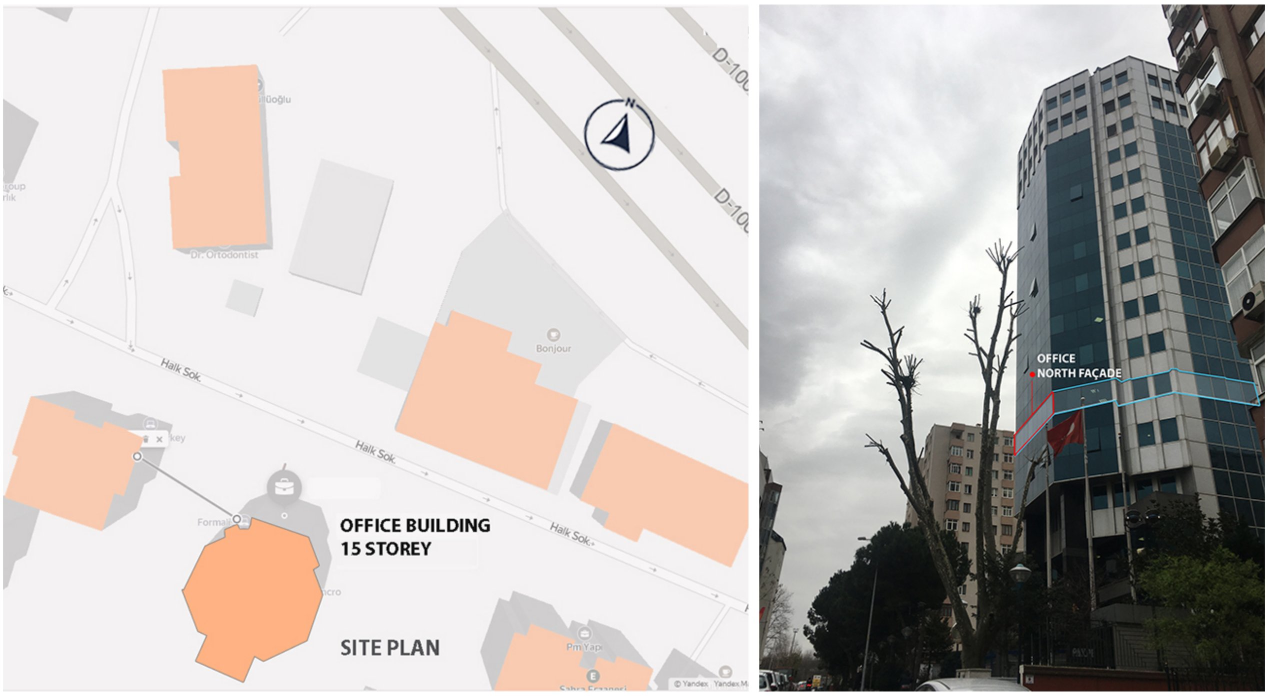


**Figure 4**. E 2, workplace site plan and building exterior view.

- Five days each in three different seasons (winter, spring, and summer) to determine the annual variation.

Measurements for Experiment 1 were carried out on 20-24 December 2022, 28 March-1 April 2022, and 22-23 June 2022. Measurements for Experiment 2 were carried out on 3-7 January 2022, 4-8 April 2022, and 27 June-1 July 2022. The study was repeated for three seasons (winter, spring, and summer months), five working days a week, for a total of 27 days, and at specific times of the day (09:30, 12:30, 16:00).

The parameters measured in the study and the characteristics of the instruments used to measure them are summarized below (Figure 7):

- **Illuminance** (E, $lm/m^2$; lx):
  - Chroma meter (Konica Minolta Chroma meter CL-200A, $Ev_K$) that measures incident light according to the sensitivity $V(\lambda)$ of the green (M) cone receptor in the eye.
  - Spectroradiometer (nanoLambda XL-500, $Ev_N$) that measures the magnitude of the radiant energy of incident light.
- **Equivalent Melanopic Lux** (EML, $lm/m^2$; lx):
  - According to the EML model approach, the $EML_K$ value was obtained by multiplying the $Ev_K$ value by

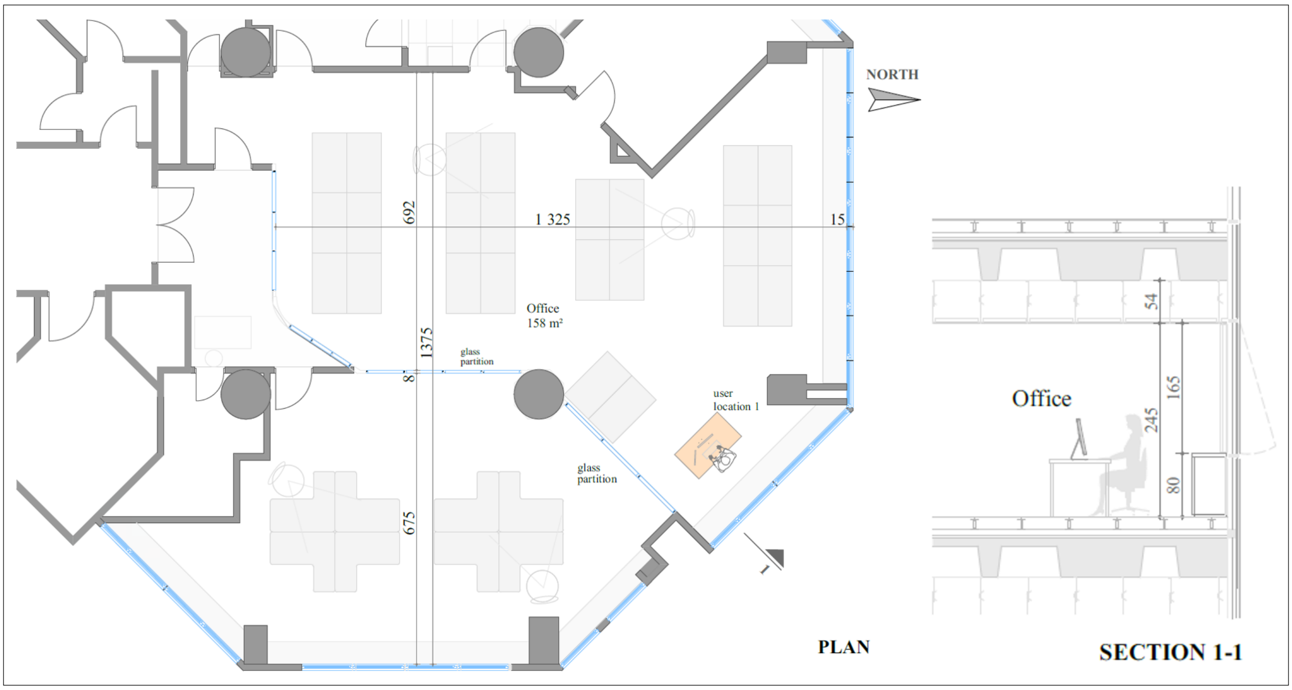


**Figure 5**. Plan and Section 1-1 of the E2 office floor.

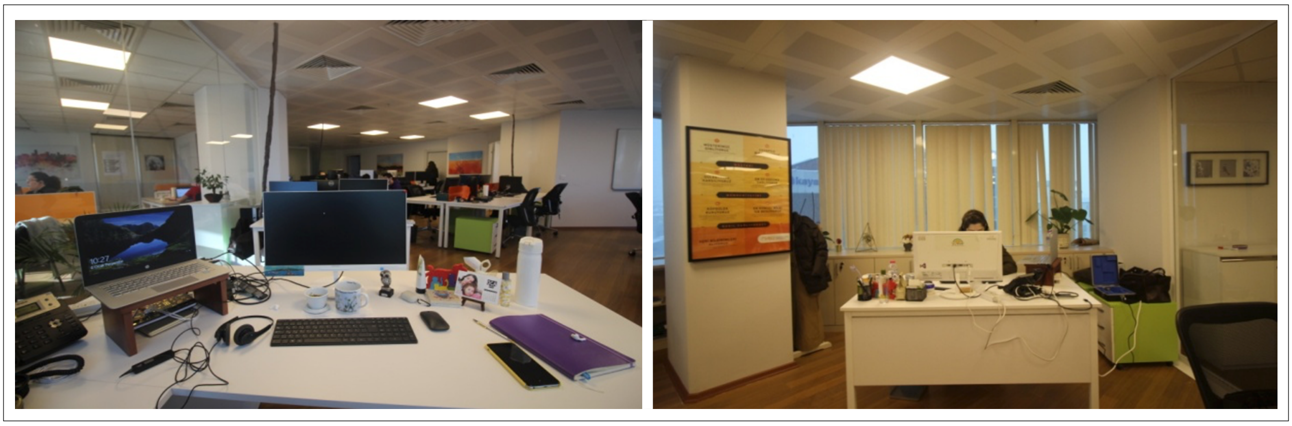

**Figure 6**. Interior view of E2 office.

the melanopic ratio determined according to the spectral energy distribution of the ambient light used. The melanopic ratio used in the study was taken as 0.76 for LED lamp (4000 K), depending on the ambient light source (International WELL Building Institute, 2021).

- The spectral luminous flux obtained with the spectroradiometer (nanoLambda XL-500), which measures the radiative magnitude of the incident light according to the wavelength, calculates the $EML_N$ value by converting the illuminance values [lx] into α-opic radiations [mW/m²] using the CIE S026 Toolbox, which is included in the software.

- **Color Temperature** (*T*cp, Kelvin):
  - Chroma meter (Konica Minolta CL-200A, $Tcp_K$) that measures incident light according to the sensitivity *V(λ)* of the green (M) cone receptor in the eye.
  - A spectral radiometer (nanoLambda XL-500, $Tcp_N$) measures the radiative magnitude of the incident light by wavelength.

The hourly weather information of the region where the experimental sites were located was recorded by following the website of the Istanbul Meteorology Directorate. The daily average weather information of the periods when the measurements were carried out is presented in Table 1.

In the experiment, illuminance and color temperature measurements were performed simultaneously with spectroradiometer measurements. The measurements were taken at eye level in the user position specified in the relevant literature at a height of 1.2 m above the floor

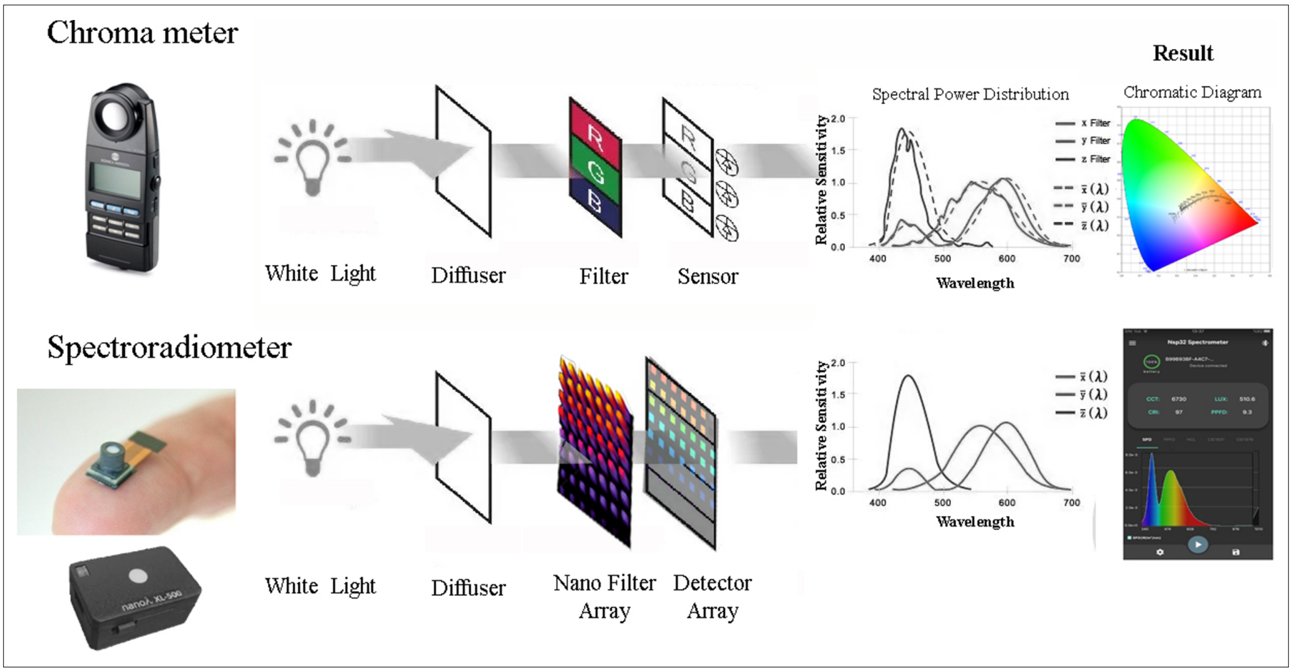


**Figure 7**. Properties of the chroma meters (photometric measurement) and spectroradiometers (radiometric measurement) used in the study.

**Table 1.** Daily average weather information of the measurement periods.

| | | | |
|---|---|---|---|
| E1 | Winter Season | Spring Season | Summer Season |
| | (20-23 November 2021) | (28 March-1 April 2022) | (22-23 June 2022) |
| | | | |
| E2 | Winter Season | Spring Season | Summer Season |
| | (3-7 January 2022) | (4-8 April 2022) | (27 June-1 July 2022) |
| | | | |

Overcast, Partly Cloudy, Clear/Sunny.

and 0.10 m behind the desk (CIE, 2018; Türk Standartları Enstitüsü, 2021).

**Comparison and Evaluation of the Results**

In this part of the study, the measurement results obtained by two different photometric and radiometric instruments at different times of the day and across three seasons in two office environments for a total of twenty-seven working days are presented, compared, and evaluated.

The measurement data obtained from the experiments were analyzed using the Wilcoxon signed-rank test and regression analysis in SPSS software. The results of the days (spring and summer periods) when different lighting scenarios (some lights off) were applied during the measurement periods were excluded from the analysis; therefore, a total of twenty-five days of data were analyzed.

In the study, the p-value represents the probability that the simultaneous measurements made with the two different devices are equal. Two different significance levels were used in the analyses for illuminance (E) and Equivalent Melanopic Lux (EML) values ($p < 0.12$) and for color temperature (Tcp) ($p < 0.05$). The recommended illuminance steps (5-7.5-10-15-20...|-5000-7000-10000 lx) to produce a perceptual difference, determined according to the lighting requirements criteria in TS EN 12464-1:2021, were used in the analysis of E and EML values (Walpole et al., 2016).

The mean vertical values of vertical illuminance ($Ev_K$, $Ev_N$), the color temperature ($Tcp_K$, $Tcp_N$), and the calculated Equivalent Melanopic Lux ($EML_K$, $EML_N$), obtained in the experiments at the same times of the day (09:30, 12:30, 16:00) and in the same seasons of the year (Winter, Spring, Summer), and the p-values are presented in Table 2 for Experiment 1 and in Table 3 for Experiment 2 (Pekin & Ünver, 2022).The p-values of the measurements that show statistically significant differences from each other are indicated with asterisk (*).

**Table 2.** The means and the p-values of the measurements obtained at the same times of the day in the same season with two different devices in Experiment 1 (user position 1).

| E1 | Winter Season (20-24 December 2021) | | | | | |
|---|---|---|---|---|---|---|
| | 09:30 | | 12:30 | | 16:00 | |
| | Mean | p | Mean | p | Mean | p |
| $Ev_K$(lm/m²) | **243** | **0.043*** | 445 | 0.138 | 221 | 0.144 |
| $Ev_N$(lm/m²) | **214** | | 382 | | 253 | |
| $EML_K$(lm/m²) | **185** | **0.043*** | **338** | **0.080*** | 168 | 0.465 |
| $EML_N$(lm/m²) | **168** | | **280** | | 163 | |
| $Tcp_K$(K) | 4525 | 0.068 | 4336 | 0.080 | 4553 | 0.068 |
| $Tcp_N$(K) | 4930 | | 4553 | | 4977 | |
| **E1** | **Spring Season (28 March-1April 2022)** | | | | | |
| | **09:30** | | **12:30** | | **16:00** | |
| | **Mean** | **p** | **Mean** | **p** | **Mean** | **p** |
| $Ev_K$(lm/m²) | 387 | 0.225 | **543** | **0.043*** | **262** | 0.080* |
| $Ev_N$(lm/m²) | 294 | | **429** | | **269** | |
| $EML_K$(lm/m²) | 294 | 0.225 | **412** | **0.043*** | 200 | 0.500 |
| $EML_N$(lm/m²) | 197 | | **323** | | 198 | |
| $Tcp_K$(K) | **4366** | **0.043**** | **4432** | **0.043**** | 4780 | 0.138 |
| $Tcp_N$(K) | **4674** | | **4726** | | 4887 | |
| **E1** | **Summer Season (22-23 June 2022)** | | | | | |
| | **09:30** | | **12:30** | | **16:00** | |
| | **Mean** | **p** | **Mean** | **p** | **Mean** | **p** |
| $Ev_K$(lm/m²) | 451 | 0.180 | 312 | 0.655 | **255** | 0.108* |
| $Ev_N$(lm/m²) | 308 | | 288 | | **276** | |
| $EML_K$(lm/m²) | 343 | 0.180 | 237 | 0.655 | 194 | 0.180 |
| $EML_N$(lm/m²) | 222 | | 210 | | 203 | |
| $Tcp_K$(K) | 4462 | 0.180 | 4538 | 0.180 | 4635 | 0.180 |
| $Tcp_N$(K) | 4663 | | 4778 | | 4918 | |

* E, EML, Statistically significant (p≤0.12); ***Tcp*, Statistically significant (p≤0.05).

In general, the Equivalent Melanopic Lux ($EML_N$) values obtained with the spectroradiometer were lower ($EML_N$ < $EML_K$) and the color temperature values were higher ($Tcp_N$ > $Tcp_K$) than those measured with the chromameter, in the experiments. On the other hand, the vertical illuminance level (Ev) values were lower in Experiment 1 ($Ev_N$ < $Ev_K$) and higher in Experiment 2 ($Ev_N$ > $Ev_K$) with the spectroradiometer.

In E1 measurements, it was found that

- $Ev_K$, $Ev_N$ Winter 9:30 am; Spring 12:30, 16:00 pm; Summer 16:00 pm,
- $EML_K$ and $EML_N$ Winter 9:30 am-12:30 pm, 12:30 pm in Spring and 16:00 pm in Summer,
- $Tcp_K$ and $Tcp_N$ Spring at 9:30 am, 12:30 pm, differed significantly.

In the E2 measurements, it was found that

- Only $EML_K$ and $EML_N$ Winter 9:30 a.m. values showed statistically significant differences, while they did not differ in other time intervals and seasons.

As expected, the quite different characteristics of the experimental spaces—the orientations of the buildings, the

**Table 3.** The means and the p-values of the measurements obtained at the same time of the day in the same season with two different devices in Experiment 2 (user position 1).

| E2 | Winter Season (3-7 January 2022) | | | | | |
|---|---|---|---|---|---|---|
| | 09:30 | | 12:30 | | 16:00 | |
| | Mean | p | Mean | p | Mean | p |
| $Ev_K$(lm/m²) | 370 | 0.893 | 362 | 0.138 | 342 | 0.138 |
| $Ev_N$(lm/m²) | 383 | | 414 | | 380 | |
| $EML_K$(lm/m²) | **282** | **0.043*** | **275** | **0.080*** | **260** | **0.080*** |
| $EML_N$(lm/m²) | **194** | | **217** | | **191** | |
| $Tcp_K$(K) | 3162 | 0.080 | 3335 | 0.225 | 3219 | 0.225 |
| $Tcp_N$(K) | 3336 | | 3406 | | 3319 | |
| **E2** | **Spring Season (4-8 April 2022)** | | | | | |
| | **09:30** | | **12:30** | | **16:00** | |
| | **Mean** | **p** | **Mean** | **p** | **Mean** | **p** |
| $Ev_K$(lm/m²) | 376 | 0.465 | 363 | 0.273 | 345 | 0.144 |
| $Ev_N$(lm/m²) | 393 | | 389 | | 405 | |
| $EML_K$(lm/m²) | **286** | **0.068*** | **276** | **0.068*** | 262 | 0.144 |
| $EML_N$(lm/m²) | **222** | | **223** | | 220 | |
| $Tcp_K$(K) | 3266 | 0.109 | 3319 | 0.068 | 3329 | 0.144 |
| $Tcp_N$(K) | 3475 | | 3565 | | 3450 | |
| **E2** | **Summer Season (27 June-1 July 2022)** | | | | | |
| | **09:30** | | **12:30** | | **16:00** | |
| | **Mean** | **p** | **Mean** | **p** | **Mean** | **p** |
| $Ev_K$(lm/m²) | **389** | **0.068*** | **281** | **0.068*** | 333 | 0.273 |
| $Ev_N$(lm/m²) | **497** | | **316** | | 363 | |
| $EML_K$(lm/m²) | 296 | 0.465 | 252 | 0.690 | **253** | **0.068*** |
| $EML_N$(lm/m²) | 319 | | 202 | | **184** | |
| $Tcp_K$(K) | 3379 | 0.068 | 3206 | 0.700 | 3150 | 0.109 |
| $Tcp_N$(K) | 3942 | | 3511 | | 3326 | |

* E, EML, Statistically significant ($p \leq 0.12$); ** Tcp, Statistically significant ($p \leq 0.05$).

different times of the day, and the various seasons of the year—significantly influence the measurements. The differences obtained with two different measuring instruments are higher in E1 compared to E2. It can be said that these differences are related to user location and building orientation. In E1, the user position is in the Southeast orientation where daylight is effective for a longer period of time. Therefore, E1 is exposed to more daylight than E2, which has a Northeast orientation and a user position parallel to the window. The variations of the photometric quantities measured at E1 and E2 according to different times of the day and seasons are presented in Figure 8.

The study also analyzed the effect of weather/sky conditions on the results obtained simultaneously with two different instruments (photometric and radiometric). The mean and the p-values of $Ev_K$, $Ev_N$, $Tcp_K$, $Tcp_N$, $EML_K$, and $EML_N$ obtained at the same time of day in the same season are presented in Table 4.

Analysis of the Ev and EML values obtained showed that the photometric (device K) and radiometric (device N) measurements differed at the level of statistical significance ($p \leq 0.12$) when daylight was dominant. It can be seen that the values obtained are significantly different in the partly

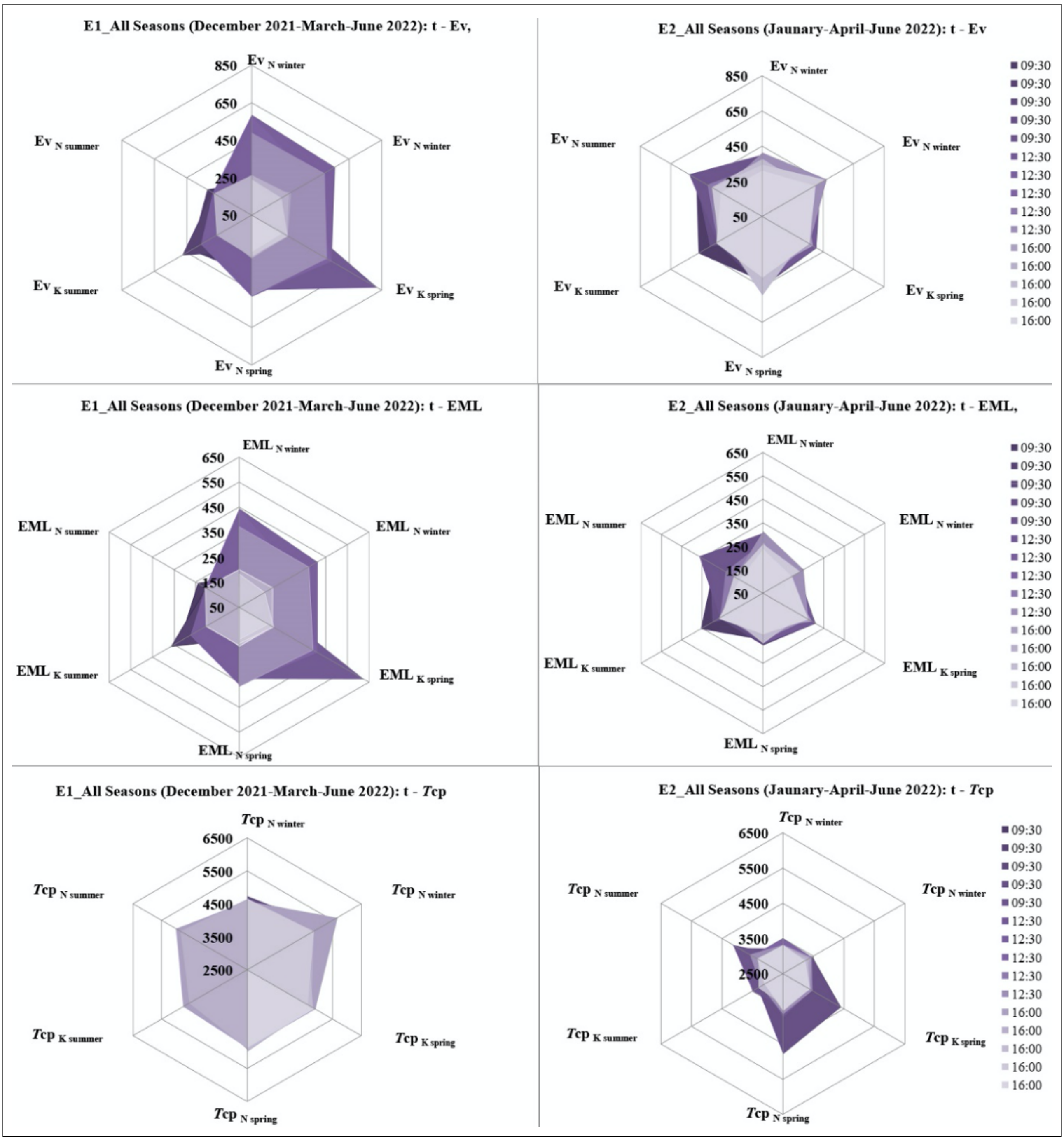


**Figure 8**. E1 and E2, Ev, EML, and Tcp values for all seasons and measurement times.

*$Ev_K$: Vertical Illuminance Level_Konica CL-200 A; $Ev_N$: Vertical Illuminance Level, Spectroradiometer_nanoLambda XL-500; $EML_K$: EvK value converted by a coefficient of 0.76; $EML_N$: Equivalent Melanopic Lux, calculated bythe Spectroradiometer_nanoLambda XL-500; $Tcp_K$: Instantaneous Measurement of Vertical Similar Colour Temperature_Konica CL-200A; $Tcp_N$: Vertical Colour Temperature, Spectroradiometer_nanoLambda XL-500.*

cloudy condition, but not in the overcast conditions. This can be interpreted as the fact that in partly cloudy weather, when the clouds are moving, the irradiance can change significantly within a few seconds, and the presence of direct and reflected daylight in the environment affects the measurement results. However, the study shows that the effect of the variation in weather/sky conditions on the measurement results according to the different months of the year (seasons) varies predominantly according to the solar declination. It can be said that the measurement differences are more pronounced

**Table 4.** Means and calculated p-values of the measurement results obtained with two different measuring devices in the experiments (E1,E2), at the same time of the day, in the same season, according to the weather change.

| | Weather Condition | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Winter | | | | | | Spring | | | | | | Summer | | | | | |
| | Overcast | | | Partly Cloudy | | | Overcast | | | Partly Cloudy | | | Partly Cloudy | | | Clear | | |
| **E1** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** |
| $Ev_K$(lm/m$^2$) | 233 | 287 | 190 | **243** | 591 | 238 | 358 | 295 | 241 | **491** | **542** | **273** | 427 | 309 | - | - | - | - |
| $Ev_N$(lm/m$^2$) | 204 | 211 | 250 | **210** | 426 | 233 | 265 | 260 | 246 | **319** | **472** | **275** | 243 | 288 | - | - | - | - |
| p | - | 0.180 | 0.180 | **0.109*** | - | - | - | - | - | **0.109*** | **0.068*** | **0.109*** | 0.180 | 0.655 | - | - | - | - |
| $EML_K$(lm/m$^2$) | 177 | 218 | 144 | **185** | 449 | 181 | 272 | 224 | 176 | **373** | **412** | **207** | 324 | 187 | - | - | - | - |
| $EML_N$(lm/m$^2$) | 162 | 151 | 140 | **171** | 316 | 167 | 196 | 192 | 179 | **202** | **356** | **202** | 181 | 210 | - | - | - | - |
| p | - | 0.180 | 0.655 | **0.109*** | - | - | - | - | - | **0.109*** | **0.068*** | **0.068*** | 0.180 | 0.655 | - | - | - | - |
| $Tcp_K$(K) | 4653 | 4609 | 4451 | 4476 | 4139 | 4657 | 4442 | 4551 | 4854 | 4255 | 4402 | 4761 | 4462 | 4538 | - | - | - | - |
| $Tcp_N$(K) | 5418 | 4644 | 5122 | 4881 | 4580 | 4829 | 4589 | 4855 | 4868 | 4492 | 4694 | 4892 | 4721 | 4778 | - | - | - | - |
| p | - | 0.655 | 0.180 | 0.109 | - | - | - | - | - | 0.109 | 0.068 | 0.144 | 0.180 | 0.180 | - | - | - | - |
| **E2** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** | **09:30** | **12:30** | **16:00** |
| $Ev_K$(lm/m$^2$) | 346 | 269 | 340 | 377 | 385 | 343 | 299 | 321 | 201 | **389** | **371** | 353 | **341** | 320 | 224 | 345 | 205 | 353 |
| $Ev_N$(lm/m$^2$) | 366 | 434 | 406 | 367 | 409 | 394 | 229 | 250 | 229 | **424** | **418** | 422 | **396** | 376 | 235 | 530 | 271 | 323 |
| p | - | - | - | 0.465 | 0.278 | 0.273 | 0.180 | 0.655 | 0.180 | **0.109*** | **0.109*** | 0.285 | **0.109*** | - | 0.180 | - | 0.180 | - |
| $EML_K$(lm/m$^2$) | 263 | 205 | 258 | **286** | **293** | 260 | 227 | 244 | 153 | **295** | **218** | 268 | 259 | 243 | 170 | 262 | 132 | 268 |
| $EML_N$(lm/m$^2$) | 175 | 223 | 171 | **199** | **215** | 215 | 137 | 157 | 197 | **246** | **247** | 230 | 256 | 196 | 128 | 364 | 135 | 166 |
| p | - | - | - | **0.068*** | **0.068*** | 0.144 | 0.180 | 0.655 | 0.655 | **0.109*** | **0.109*** | 0.285 | 1.0 | - | 0.180 | - | 0.655 | - |
| $Tcp_K$(K) | 3283 | 3136 | 3145 | 3132 | 3385 | 3238 | 3734 | 3625 | 3385 | 2242 | 3409 | 3380 | 3628 | 3166 | 3401 | 3493 | 3412 | 3107 |
| $Tcp_N$(K) | 3226 | 3350 | 3409 | 3364 | 3420 | 3296 | 4015 | 4127 | 3580 | 3626 | 3668 | 3464 | 4135 | 3373 | 376 | 4145 | 3902 | 3348 |
| p | - | - | - | 0.068 | 0.465 | 0.465 | 0.180 | 0.180 | 0.180 | 0.109 | 0.109 | 0.285 | 0.109 | - | 0.180 | - | 0.180 | - |

* E, EML, Statistically significant ($p \leq 0.12$). ** $Tcp$, Statistically significant ($p \leq 0.05$).

in the winter and spring seasons when the sun's rays are more tilted, than in the summer period.

It was observed that the Equivalent Melanopic Lux, EML values obtained in both experiments generally met (see Table 2, Table 3) or were close to the 200 EML value recommended for the hours specified in the EML metric (between 09:00-13:00). It is seen that the lowest EML values were obtained in the winter period. In general, it can be said that both instruments can be considered for measuring also the non-visual effect of light with close accuracy.

## DISCUSSION AND CONCLUSION

Visual and non-visual effects of light are critical for public health. Improving physical environmental conditions and regulating the amount of light reaching the eye has a positive effect on quality of life, well-being, and aging. In recent years, this effect of light on health has become one of the basic requirements of modern society. Lighting designers need a precise and simple tool or guideline to calculate/estimate the photopic and melanopic illumination at eye level and to determine how this illumination can be improved/supported in each case with respect to the current situation. However, despite various measurement methods and equipment and existing recommendations, it cannot be assessed in a sufficiently accurate/quantitatively scaled manner.

This article, which is limited in scope, presents some findings and evaluations of a study that investigated whether the data obtained by using two different measuring devices with different methods for detecting the non-visual effects of light in closed working environments would affect the accuracy and reliability of the measurements, depending on the measurement time and the characteristics of the measurement environment.

The results of two experiments (E1 and E2) carried out in two different offices as part of the research can be briefly summarized as follows:

- Significant differences were observed between photometric and radiometric measurements for different times of the day (morning, noon, afternoon) and different periods of the year (winter, spring, and summer).
- It is clear that the orientation of the buildings, and hence, the offices E1 and E2, has a clear effect on the measurement results. Differences between the results of photometric and radiometric measurements were found to be higher in E1 than in E2. This situation can be attributed to the fact that daylight is effective for a longer period of time during the day in E1 with a southeast orientation that is related to the visual field of the participant.
- It was found that the weather/sky condition has an effect on the Ev and EML measurement results. Photometric and radiometric measurement results were significantly different in partly cloudy sky conditions compared to the overcast condition. This can be interpreted as the effect of sky conditions/daylight on the measurement results.
- It can be said that the EML values generally meet the 200 EML value recommended for the hours specified in the EML metric (between 09:00-13:00) in all measurement periods, and that both instruments can be considered to measure the non-visual effect of light with close accuracy.

In other words, when the measurement results of the illuminance meter and chroma meter, which evaluate the ambient light according to the sensitivity of the cone receiver in the eye (M), and the measurement data of the spectroradiometer, which measures the radiant magnitude according to wavelength, are compared, it is seen that there are statistically significant differences in the results obtained according to the measurement time (09:00, 12:30, 16:00) and measurement period (December-January, March-April, June). However, most of the other differences between the instruments are not significantly large when compared by season. This phenomenon can be attributed to the differences in the functioning/operation of the two measuring instruments.

Luminance meters are more advantageous than spectral radiation meters in terms of accessibility and cost. For this reason, in studies aiming to quantitatively determine the non-visual effect of light, it can be said that studies with a light source with a known spectral energy distribution and melanopic ratio can be carried out with illuminance meters or colorimeters.

In summary, the values obtained by measurements and calculations in experiments vary with the measuring instrument and method used. However, the levels of statistical significance can reveal very useful information about the selection of measuring instruments and methods to be used in research and the traceability of their calibrations. It reveals that it is necessary to know what the measuring device and the calculation method used in the studies measure, and with what accuracy. It can be said that this will help researchers make more accurate judgments with more meaningful data in experiment design.

In conclusion, the above information shows that the non-visual effects of light also can be analysed with the two different measurement methods, but it also shows that there are differences between them. The research, which was initiated to determine the non-visual effects of light on users of indoor working environments some of which is reported in this article is being continued by extending it to examine the effect of measurement methods on the measurement results.

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