System of Circadian Lighting Based on Determination of Human Thermal Comfort Level

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Abstract: Comfortable level is an important element that has considerable implications on circadian energy and the perception of lit environments. Light has been also defined in terms of the circadian system, but not only for human vision. Light source and systems development should consider the needs of both the visual and non-visual systems. Many complaints about indoor conditions are related to unsatisfactory thermal environments. Most research on Thermal Comfort (TC) considered physical parameters for settings and users yet marginalized the influence of user's psychological aspects in the process of thermal sensation. This research examines the effect of mood states on human evaluation of the thermal environment in virtual settings. There are ten university participators from Technical university of Dresden have taken part in experiments. The experiment followed the "Lab 2.0" using climate controlled chamber and TC evaluation using psychological responses. Linear model was used to analyse the data. The results revealed a relationship between TC, mood state and quality of the indoor environment. Humans' judgment on TC is a variable mental reaction. The research presents differences between the evaluation people to their thermal environments. This study expands research on the indoor environment quality and develops TC evaluation strategies.

1 INTRODUCTION

We spend most of our time indoor in artificial thermal environments which affect human beings. Properly designed indoor environments are essential for pleasant living and optimized task performance in the work place. Amongst other parameters, Thermal Comfort (TC) level is one of the scales that measure human`s solace in physical settings. It indicates the thermal balance of the body as determined by the operative temperature and moderated by environmental and personal parameters.

Lighting systems allow to adjust the individual characteristics and human healthy demands. Particularly, during adjusting the lighting parameters, it is possible to create a positive effect on a human circadian rhythms. The violation of these rhythms is an important problem during the durable operation of computers or laptops [1].

In this article lighting will be describe through the connection between thermal and circadian lighting. Circadian lighting means lighting that coincides with our circadian system for the entire day. Outdoor lighting changes color throughout the day from a warm lighting to a cool daylight color and again to a warm color [2]. It is important to pay attention that circadian lighting isn't limited to light bulbs and fixtures, it includes electronic devices as well.

Studies on TC are classified within the domain of the physical and technical sciences. Three major trends of TC studies were identified: positivistic and reductionist approach, multivariate and systems-oriented approach and applied and conservation oriented approach [3]. The former is a physical and laboratory-based trend, which exported set of standards, indexes and bioclimatic charts in indoor and outdoor thermal conditions.

This article reports a multi-domain (thermal and visual) comfort investigation, aiming to identify whether the colour of light affects the human thermal perception. For this, it was planned an experiment associating different thermal settings and colours of light.

It is also important to receive measurements in order to realize electronic system of lighting.

2 THEORETICAL PART OF CIRCADIAN AND COMFORT THERMOLIGHTING

2.1 Radiation Lighting in Case of Temperature Field

Lighting is a fundamental requirement of our daily life, especially for human circadian rhythm. The effect of light, which is emitted by electronic devices, has either positive or negative effect on a person, even if it does not get in contact with your eyes [4].

Decades of research demonstrate that radiation responses vary across an organism's circadian period. The emerging field of chronoradiobiology examines the biological relationships between the complex mechanisms of circadian regulation and cellular radiation responses with the goal of improving the therapeutic index of radiation treatments.

Understanding circadian regulation, disruptions, and downstream effects that can impact radiation therapy could lead to potential improvements for patients. Data on circadian disruption and clock gene regulation may lead to new approaches to personalize care [5].

2.1.1 Wien's Law and Connection Between Room and Color Temperature

Radiation laws of the black body: The black body represents an ideal radiation body. This means that the entire incident radiation is absorbed by the black body and also emitted again. Since this assumption assumes thermal equilibrium, the temperature of the black body does not change either [6, 7].

Radiation temperature must be relatively low because of the anti-proportional relationship between wavelength λ and temperature T due to Wien's displacement law (1) (DIN 5031-7 1984).

$$\lambda_{\max} = \frac{2897.8 \mu m \cdot K}{T} . \tag{1}$$

It is important in our work to find connection between room and lighting temperature in order to make some basically explanation of lighting impact on thermal comfort.

The position of the radiation maxima can be determined using Wien's displacement law

$$E = \frac{2\pi h c_0^2}{\lambda^5 \left[\exp\left(\frac{h c_0}{k_B T_{room} \lambda} \right) - 1 \right]} , \tag{2}$$

where coefficients $h = 6.63 \cdot 10^{-34}\, Joule/s$ − Planck constant, $c_0 = 3 \cdot 10^8\, m/s$ − speed of the lighting, $k_B = 1.38 \cdot 10^{-34}\, Joule/K$ − constant of Boltzmann, T_{room} − air temperature inside of the room or chamber ($T_{room} = 19...25°C$), λ − wavelength of radiation $[nm]$, S − area of falling light $[m^2]$, r − distance between eyes and lighting source $[m]$.

After the series of transformation (2) were transformed into (3)

$$I = \frac{E}{S} = \frac{2\pi h c_0^2}{S\lambda^5 \left[\exp\left(\frac{h c_0}{k_B T_{room} \lambda} \right) - 1 \right]} \Rightarrow \frac{I}{r^2} = \frac{2\pi h c_0^2}{r^2 S \lambda^5 \left[\exp\left(\frac{h c_0}{k_B T_{room} \lambda} \right) - 1 \right]} \tag{3}$$

where I − intensity of lighting $[W/m^2]$, I/r^2 − relation for illuminance $[lx]$,

Illuminance describes the quantity of luminous flux falling on a surface. It decreases by the square of the distance (inverse square law). Relevant standards specify the required illuminance (e.g. EN 12464 "Lighting of indoor workplaces") [8]. Equation (3) were transformed into (4):

$$illu\min ance = \frac{2\pi h c_0^2}{r^2 S \lambda^5 \left[\exp\left(\frac{h c_0}{k_B T_{room} \lambda} \right) - 1 \right]} = \frac{2\pi E c_0}{r^2 S \lambda^4 \left[\exp\left(\frac{E}{k_B T_{room}} \right) - 1 \right]} \tag{4}$$

Equations (1) and (4) are basically in order to calculate and receive connections between lighting parameters and climate parameters, especially room temperature.

2.1.2 Representation of the Different Kinds of Electric Light Sources.

Light, the basis for all vision, is an element of our lives that we take for granted. We are so familiar with brightness, darkness and the spectrum of visible colours that another form of perception in a different frequency range and with different colour sensitivity is difficult for us to imagine. Visible light is in fact just a small part of an essentially broader spectrum of electromagnetic waves, which range from cosmic rays to radio waves [9].

Human eye can experience a specific portion of the electromagnetic spectrum, which referred as 'Visible light' in Figure 1 [10]. Radiant energy from light is transmitted, absorbed or reflected, when it strikes a surface. From observer's point of view, color of surface is only visible if the frequency of the spectrum reflected back to the eye of observer. The brighter the surface, the occurrence rate of reflection increase, likewise, darker surfaces absorbs more radiant energy with minimal reflection.

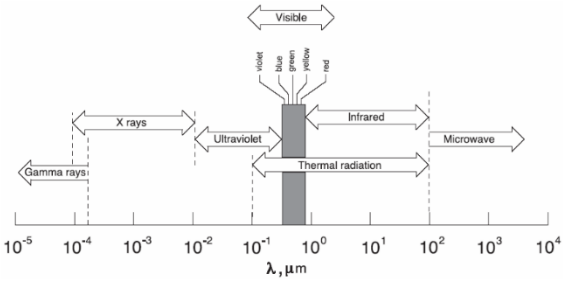


Figure 1: Electromagnetic spectrum.

Electric light sources can be divided into two main groups, which differ according to the processes applied to convert electrical energy into light. First group comprises the discharge lamps; they include a wide range of light sources, e.g. all forms of fluorescent lamps, mercury or sodium discharge lamps and metal halide lamps. Second group comprises the thermal radiators, they include incandescent lamps and halogen lamps.
Low-pressure and high-pressure lamps belong to the category of "Discharge lamps". This means, that they do not leave a lot of heat during the working process.

The electric discharge lamp is family of artificial light sources that generates light by sending an electric discharge through an ionized gas. In all types of electric discharge lamps, an electric current is passed through a gas or vapor which renders it luminous. The most commonly used elements in these types of lamps are neon, mercury and sodium vapors as in Figure 2.

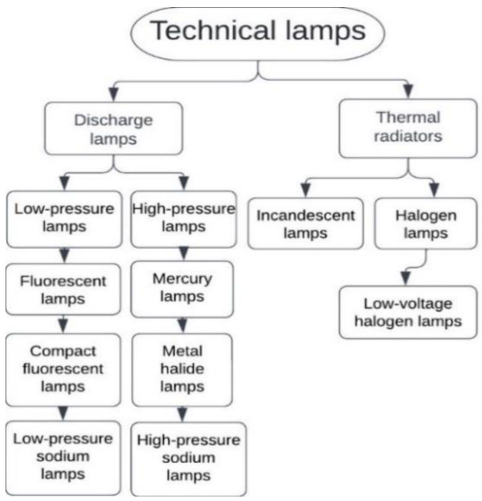


Figure 2: Kinds of electric light sources according to the means of their light production.

The advantages of electric discharge lamps are: longer life, operating cost is low, discharge lamps can be designed for different colors, and, of course, produce less heat [11]. Last aspect was taken into account for experiment.

2.2 Circadian Rhythm and Circadian Lighting

This "Circadian rhythms" [12] mean changes in physiological, biochemical and behavioral functions of the body. These rhythms are synchronized with the natural light dynamics of the surrounding world ("day and night") by means of internal molecular "hours", surround temperature, humidity and other conditions. Circadian rhythms are also 24-hour cycles that are part of the body's internal clock, running in the background to carry out essential functions and processes. One of the most important and well-known circadian rhythms is the sleep-wake cycle.

Human organism can adopt to the certain time of the day and the different systems of the body follow circadian rhythms that are synchronized with a master clock in the brain. This master clock is directly influenced by environmental cues, especially light, therefore circadian rhythms are tied to the cycle of day and night.

As properly aligned, a circadian rhythm can promote consistent and restorative sleep. But if this circadian rhythm is thrown off, it can create significant sleeping problems for the organism, including insomnia. Earlier researches are also revealing that circadian rhythms play an integral role in diverse aspects of physical and mental health.

Certain list of circadian rhythm with a certain time and characteristic of human organism was represented in Figure 3. This shows certain period of time, when people have highest or lowest either blood pressure, and body temperature; time of deepest sleep and so on.

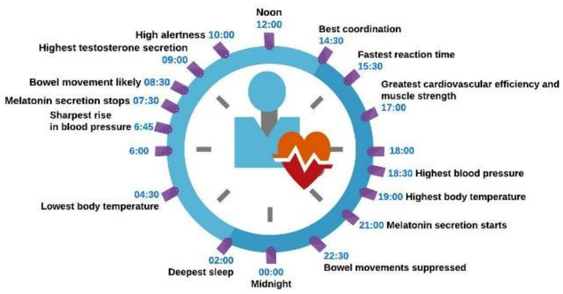


Figure 3: Circadian rhythm during the different period of day.

The terms circadian and integrative lighting are now often used interchangeably [13]. Throughout this report, we have chosen to use the term circadian lighting, as the project was funded for studying circadian lighting, lighting that is intended to support the natural sleep and wake cycle of humans that is normally entrained by the presence and absence of naturally varying daylight.

Research has indicated that light affects on the human healthy both of non-visual and our visual systems and that electric light can make impact on circadian rhythm [14]. Circadian lighting is the concept that electric light can be used to support human healthy by minimizing the effect of electric light on the human circadian rhythm. Research workers have discovered that long-term exposure to certain wavelengths of blue light at a specific intensity can have either positive or negative impact on melatonin production. The conception of using lighting to influence human circadian rhythm is a relatively new one in the lighting industry: all aspects of this exciting new topic are still being studied for a long time, and the current data is still in its infancy. Nowadays, there are three main electric light approaches to implementing a circadian lighting system: intensity tuning and stimulus tuning.

Intensity tuning is the most familiar and cost-effective solution to circadian lighting. Fixtures maintain a fixed correlated color temperature (CCT) while the intensity (brightness) of the fixture is adjusted, through a controlled dimming system, to correlate with time of day. Light fixtures are set to a lower intensity in the early morning, transition to a higher intensity as the day progresses, and reduce to a lower intensity in the evening.

Color tuning involves changing the light intensity and CCT to mimic the daytime/nighttime cycle. We experience cooler color temperatures (ranging from 4000 Kelvin up to about 10,000 Kelvin) when the sun is highest in the sky and people are typically most alert during the day. Therefore, cooler CCTs are used in spaces and during times when it’s appropriate to promote alertness and attention. Warmer color temperatures (ranging from < 2700K to 3500K) represent daylight hours when the sun is rising and setting when people are falling asleep or waking up. Circadian lighting systems are set to adjust based on the CCT we typically observe at any given time of the day.

Stimulus tuning is lighting technology that replaces the “blue light hazzard” with “good blue” light wavelengths. This circadian lighting approach more closely mimics the daylight natural spectrum. Stimulus tuning light fixtures can be programmed for reducing blue light wavelengths during the evening/nighttime hours to limit melatonin suppression without changing the CCT. This lighting approach is similar to color tuning and is the most effective when paired with intensity tuning [15]

The consequences of circadian rhythm disturbances are reduced sleep quality, drowsiness, low work productivity and bad mood. The effect of radiation on the human body includes visual perception, influence on the psychophysiological and emotional state. At the same time, there is damage to the elements of the eye and skin, as well as a number of other negative factors for physical health (photobiological danger).

2.3 Main Aspects for Visual Comfort Circadian Lighting

Most of all visual comfort can be usually defined through a set of criteria based on the level of light in the room, the balance of contrasts, CCT and the absence or presence of glare [16]

There are actually many different definitions of visual comfort level and what people should measure as part of it.

The most widely used and accepted metrics tend to focus on:

- The measure or the quantity of natural light over the year: the potential of the certain building and its location to provide enough daylight to occupants. This is typically explored through daylight autonomy or through the useful daylight illuminance;;
- Lighting distribution as perception: whether a space will be too highly contrasting or too bright;
- Another aspects: there are another conceptions that don’t have a metric but on which academics widely agree. The quality (through its spectral) of a view is also a consideration but is hard to quantify; however, the first methodologies are starting to appear.

During our research, office conditions will be accept. Actually, in cellular offices, good conditions have been observed in general and giving the users full responsibility for controlling their own indoor climate during occupied hours works very well. The occupants have demonstrated a sparing use of supplementary mechanical cooling/heating equipment. They appear to have a preference for using windows and clothing to modify conditions in mild mid-season weather. However, most occupants appear to have upper and lower “tolerance” limits, beyond which active intervention will be applied if the opportunity is available [17].

The control strategy should determine both time and rate control. It should also determine different control modes in relation to different weather conditions. The actual control strategy should reflect the demands of the building owner, the needs of the users and the requirements in standards and regulations [17, 18].

Therefore, actual task of the work is defining of comfort temperature and dates, which are suitable and comfort for humans, who are staying in the office for a very long time.

3 METHODS OF RESEARCHING

3.1 Climate Chamber at the Technical University of Dresden

For experiment was used climate chamber at the Technical university of Dresden.

The physical behavior of the climate room is extremely flexible. The climate room at the TU Dresden (Figure 4) has an inner dimension of [19].

The interior surfaces are divided into 73 individually tempered surface areas and the connected ventilation system can be controlled by temperature, humidity and volume flow. In order not to exert any significant influence on the measurement results, the ventilation system only serves to supply the subjects with fresh air during the test.

Activities are currently underway at various scientific institutions that focus on refining the local comfort models and on checking the global comfort models.

Figure 4: Circadian rhythm during the different period of day.

The surface temperatures of the walls, ceiling and floor can be regulated in a range of T = 10 … 50 °C. Air volume flow maximal, actually maximal volumetric flow per unit time 600 m³/h.

In order to define important for measuring parameters of lighting there were used optical devices. There are digital color temperature sensor and illuminance device FLAD23CCT with ALMEMO D6-connector [20], which were used during the experiment, are in Figure 5.

Figure 5: Color temperature sensor with device ALMEMO 2590-2.

Certain technical dates for measuring device are represented in Table 1.

Color temperature and illuminance are determined as a means to plot and evaluate lighting systems.

Digital color temperature sensor with “TrueColorSensorchip” and integrated signal processor “The TrueColorSensorchip” (3 sensors on 1 chip) detects - separately - each of the three colors - red, green, blue (RGB). The respective sensitivities of these 3 color sensors are adapted to the standard spectral curves as per CIE and DIN. On the basis of these RGB values the computer calculates the color point within the RGB range in terms of coordinates X and Y and determines the correlated color temperature (CCT) in Kelvin.

Compact sensor, particularly suitable for mobile applications. The display shows simultaneously both this color temperature and the illuminance in a range of lux (lx) or kilolux (klx).

Device as in Figure 5 is useful both for measuring of lighting, and different climate parameters such as for example air temperature, humidity level and list of others.

Table 1: Technical dates for measuring devices.

Spectral sensitivity	380 nm - 720 nm
Correlated Color Temperature (CCT)	10...65,000 lux (factory settings) or 0.05...170.00 kLx
Illuminance V-Lambda:	10...65,000 lux (factory settings) or 0.05...170.00 kLx
Room temperature conditions	-10…+40 C°
Refresh rate:	1.5 seconds for all channels
Settling time:	3 s (when operating the data logger in sleep mode, a sleep delay of 3 s must be programmed)
Supply voltage	6...13 V DC

During the experiment test people are sitting in the middle of the room and accepting the light as represented in Figure 5 There is represented front view a), side view b) and plan view c) with an area dimension and lamps, each of the lamps numbered, has a certain dimension and Guth position index (p_1, p_2, p_3, p_4) [21]. More detailed information about Guth position index and another parameters can be found in [22]. Lighting in Figure 6 is represented in case of arrows.

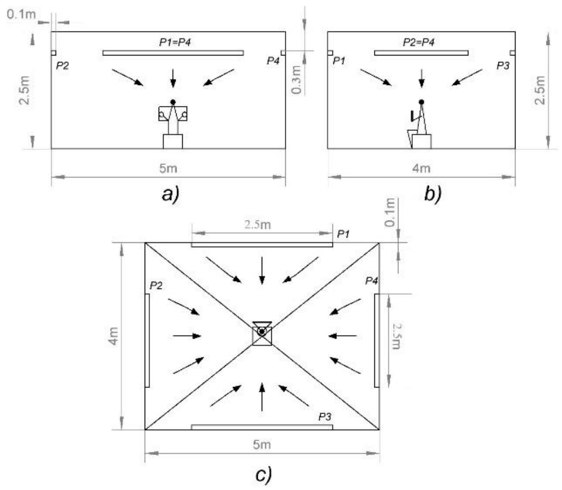


Figure 6: Schematic representation of elevation and person, which is sitting in the middle of the room: a) front view; b) side view; c) plan view.

Person in Figure 6 can be represented with a big scale as in Figure 7. There is explanation of siting person position.

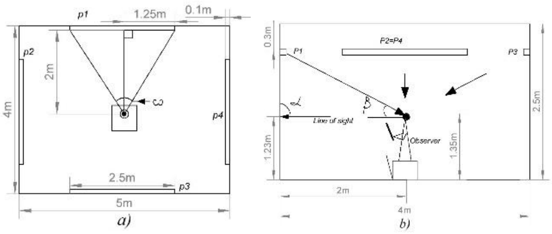


Figure 7: Detailed schematic representation of the test person a) plan view; b) side view.

3.2 Experiment Task and Participants

One of the tasks for measuring is defining of human comfortable level. There were prepared special conditions in order to define impact on human comfortable level through the lighting and to confirm some theoretical moments between lighting parameters and comfort parameter.

Participants. There are five persons were called for an experiment, especially boys and girls. Each of them has been interviewed before experiment about different biological and personal parameters: age, sex, how did people get to the labor (bicycle, walking, car or something else), height, weight, first imagination of temperature feeling (hot, warm, cold) in the climate chamber.

3.3 Realization

During the experiments, both Correlated Color Temperature (CCT) and illuminance are only variable parameters. Another parameters such as room and surface temperature, airflow are constants.

The influence of brightness on human sensation has been extensively studied in the past and is also established in various standards and regulations. In order to be able to assess the influence of color temperature on the thermal sensation of humans, tests are currently being carried out on test persons in the Combined Energy Lab of the TU Dresden [10]. A uniform operative room temperature of 22°C is set in the indoor climate room. One result could be that at the selected operative room temperature of 22 °C, the thermal sensation of the test persons is influenced by the choice of color temperature - "warm" light could provide a higher thermal sensation than "cold" light. If this correlation can be shown, this obviously has a very great potential for the operation of a heating system or its energy consumption as well as CO2 emissions.

With the help of LED lighting, the color temperature can be varied in the range of T = 2600 ... 4400 K and brightness can be varied in the range of 79…250 lx. This results in a three-stage experiment with color temperatures T1 = 2600 K, T2 = 3500 K and T3 = 4400 K with constant ambient conditions (room perimeter surfaces and supply air have 22 °C).

The color temperature is thus the only variable influencing thermal comfort. The test person answers an online questionnaire based on DIN EN ISO 28802 every 5 minutes. Experiment passes during the certain period of day-time: either in the morning, or in the afternoon.

Figure 8 shows one of the example of colour temperature changing in climate room.

Figure 8: Experimental setup, left T1= 2600 K, right T3 = 4400 K.

There are some more conditions:

- test person must not use any other devices such as computers, mobile phones, tablet or any other lighting devices;
- each test person has a right to take along either book or newspaper;
- each test person has a right to take along a bottle of water and drink it.

4 METHODS OF RESEARCHING

4.1 Results of Lighting Calculations

There were different participants, who have already taken part during the experiment. Certain information about biological and personal parameters, which were mentioned in Section 3.2, are shown in Table 2. During the each position there people must sitting on the chair in the middle of the room.

Dates in Table 2 are important and it is possibility to compare lighting impacts on the human, who has certain individual characteristics. Unfortunately, there are only 5 test persons, but the acute accent was taken not on statistical research, but searching for common zone, which would be comfortable for each test person.

Table 2: Personal parameters of test persons.

Number of person	Age	Sex	Person gets to university	Height, cm	Weight, kg
1	25	male	On feet	181	76
2	39	female	On feet	171	76
3	29	male	On feet	180	71
4	33	male	On feet	170	80
5	23	male	Bicycle	172	

As it was mentioned above, each test person had to answer online questionnaire every 5 minutes. Here are some results of experiment in Figure 9 a) and 9 b).

Table 3 shows lighting conditions, which were used during the experiments.

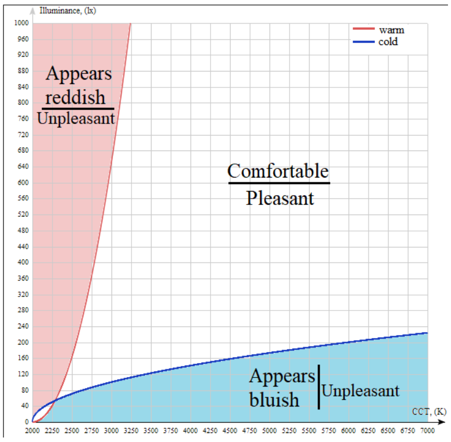
Table 3: Experimental middle measuring results based on questionnaire of one of the statistical person.

Questionnaire of one of the statistical person							
Time	Period	Phase	CCT, K	Brightness, lx	Feeling of room temp.	Did you feel any changes	Do you agree with temp.
9:23		Clear all date	4400	222			
9:46		Test realization	4172	81	Something warm	Cooling	Yes
9:55	0:00	Phase 1	4133	85	Neutral	Cooling	Yes
10:15	0:20	Start of Pause	4138	84	Neutral	Cooling	Yes
10:20	0:25	Phase 2	3346	69	Something cold	Cooling	Yes
10:40	0:45	Start of Pause	2600	78	Neutral	No changes	Yes
10:45	0:50	Phase 3	2600	85	Neutral	No changes	Yes
11:05	1:10	Finish	2600	88	Neutral	No changes	Yes

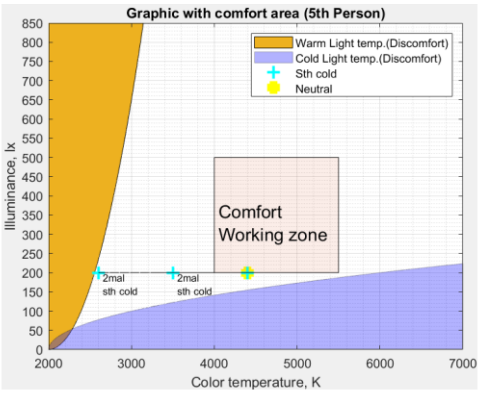
All the results obtained from the tested persons were then processed and brought to Kruithof coordinate plane that contains two curves:

- hyperbolic function for bluish or cold colour temperature $y = \sqrt{10(x-2000)}$;
- parabolic function for reddish or warm colour temperature $y = (x-2000)^2/1538.46$.

Final curves are shown on Figure 9 where a) presents the approximation of Kruithof curves with a square of cold and warm colour temperature. At the same time there was received an experimental measuring results based on questionnaire of the statistical persons b). Square in the center of graphic is «comfort zone», which is limited by four direct lines ($CCT_1 = 4000K$, $CCT_2 = 5500K$, $E_{V1} = 200lx$, $E_{V2} = 500lx$) and shows the most pleasant zone for a work.



a)



b)

Figure 9: Practical realization of Kruithof curves with an: a) warm and cold color temperatures; b) results based on experiments with one of the test persons.

Comfortable thermal lighting has background connection with adaptive lighting.

Adaptive lighting means lighting that could automatically adjust to the certain color temperature of your smart lights throughout the day to better match human circadian rhythm and the light outside.

An adaptive lighting system automatically adjusts its light output and operation to provide targeted light levels based on environmental conditions, user schedules, or other application specific criteria. An adaptive system can also often be manually tuned, over time, in terms of light level, and in some cases, color, to provide optimal lighting conditions as designated by system operators, building owners or occupants. This feature set is accomplished by combining controllable luminaires with lighting controls and communication hardware that are able to interpret changes in the environment and adjust the luminaires accordingly [23].

According to equations (2) and (5) for lighting parameters, there was received certain connections between lighting parameters. First of all parameters of color temperatures $CCT_1 = 4000K$ and $CCT_2 = 5500K$ were taken into account, the next point is illuminance for a working process ($E_{V1} = 200lx$ and $E_{V2} = 500lx$), and the last one is range of visible lighting between $\lambda = 380nm$ and $\lambda = 700nm$.

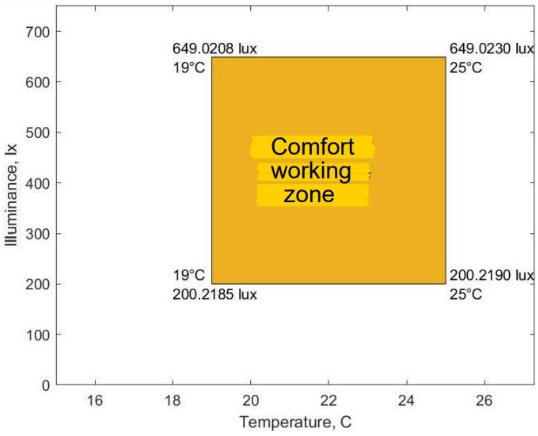
As the result, there were built graphics, which can in the best way show dependence between lighting parameters (room temperature and color temperature). Certain dependence is represented in Figure 10.

Table 4: Connections between lighting parameters.

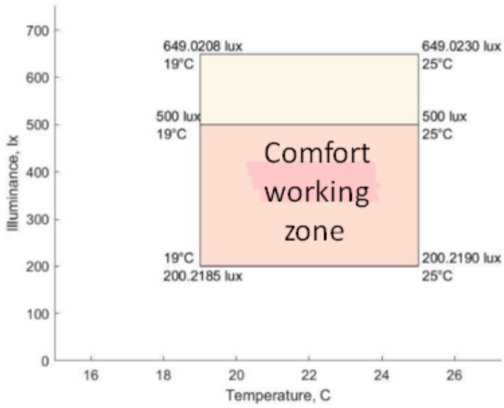
λ, nm	T_{farb}, K	E^*_{Joule} 10^{-27}	*illuminance, lux*
724.5	4000	2.745	132.0219
526.9	5500	3.775	649.023
594.16	4877.4	3.3476	500
700	4140	2.841	200
380	7626	5.234	3326.2
700	4140	2.841	200.219

According to (4), there was received graphic as in Figure 10 a).

It is also important to take into account restriction in Figure 9 b), especially range of illuminance $E_V = 200...500lx$ for office work. As the result, it was received graphic in Figure 10 b).



a)



b)

Figure 10: Connection between illuminance and room temperature: a) common situation; b) situation according to Kruithof curve.

As the result of Table 4, there were received 3-dimensional zone for comfort zone in Figure 11, which could theoretically passed according to results of calculations.

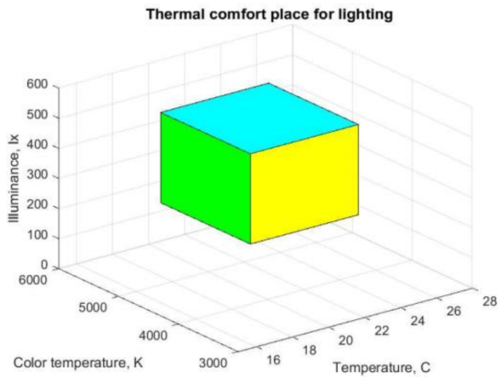


Figure 11: 3D-model of thermal comfort with connection between illuminance and room temperature.

4.2 Results of Human Questionnaire

According to answers during the experiment, there were received the results, which are represented in Table 5 and Table 6 and appropriate graphics in Figure 11 and Figure 12.

Some questions during the questionnaire were connected with acceptations and opinion about level of room temperature. In Table 5 there are characteristics in range of "freeze-cold-something cold-neutral-something warm-warm-hot" and answers, which prefer test person.

Certain dates for each color temperature in Table 5 were also represented in Figure 13.

Table 5: What does test person think about room temperature, especially feeling of room temperature.

Question:	What do you think about room temperature?						
Options:	freeze	cold	something cold	neutral	something warm	warm	hot
Meaning:	-3	-2	-1	0	1	2	3
Color temperature	Number of responses by subjects during the last two surveys						
2600		2	4	4	0		
3500			4	5	1		
4400		2	3	5	0		

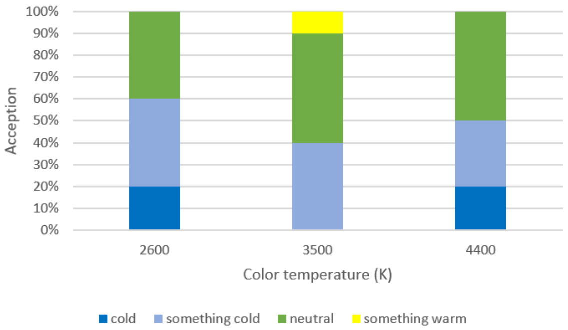


Figure 12: How does test person accept actual room temperature.

Another question during the questionnaire was connected with agreement with room temperature.

Table 6: What does test person think about room temperature, especially feeling of room temperature.

Question:	Do you agree with room temperature?	
Options:	No	Yes
Meaning:	0	1
Color temperature	Number of responses by subjects during the last two surveys	
2600	2	8
3500	2	8
4400	3	7

Certain dates for each color temperature in Table 6 were represented in Figure 13.

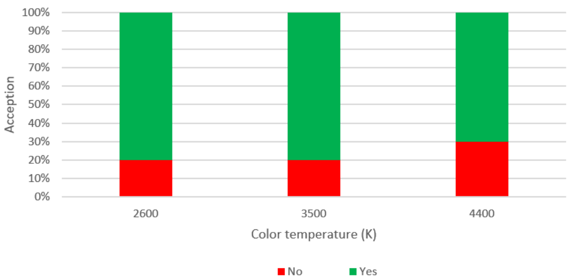


Figure 13: Does test person accept actual room temperature.

There are many different particular characteristics of human organism and certain results need more processing. But people can image which of color temperature can be acceptable, when both air parameters, and room temperature are constant. It is a background for creating a graphic for Sample Standard Deviation. As the result, it will be receive zone of agreement combining both common zone of actual room temperature, and zone of air acceptations.

By the way, principle of fuzzy logic will be used in order to define correct point in a certain period of time as in [22]. It will be done through the system IoT.

5 CONCLUSIONS

The optimal CCT is more beneficial than increased illuminance in moderate ambient indoor lighting, as it provides better lighting comfort.

This work is dedicated to the development of "smart lighting in the building" systems that create a positive impact on the physiological properties of human. By applying IoT and sensor technology we designed and implemented a smart lighting system, which can dynamically control lighting environment inside a room.

During the projecting of lighting systems, the choice of color temperature and spectral composition of sources should be carefully considered in order to avoid disruption of natural circadian rhythms or, if necessary, to increase the efficiency of human physiological parameters (for example, daytime or nighttime working period). Particularly, the beginning of the color temperature is in the numerical range of 4000-5500 K.

There was defined original and practical zone from “Kruithof curve”, which forms square “Comfort working zone”, which is limited by four direct lines ($CCT_1 = 4000K$, $CCT_2 = 5500K$, $E_{V1} = 200lx$, $E_{V2} = 500lx$) and shows the most pleasant zone for a work.

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