Design of UVB-LED Lighting System to Support the office Worker's Synthesis of Daily Vitamin D

Kyeong-Mi Kim, Young-Won Kim, Seung-Taek Oh, Jae-Hyun Lim

***Abstract:**Vitamin D is supplied through skin synthesis by exposure to ultraviolet-B (UVB), as well as dietary intake, and plays a pivotal role in maintaining human health. Duration of exposure to UVB, however, has rapidly increased recently because of modern people's excessive use of UV cream, type of clothes worn, and increase in duration of staying indoors. In this regard, this study suggests a UVB-LED lighting system to meet the daily target amount of vitamin D among office space occupants. The suggested system calculates the synthetic amount of vitamin D by sensing outdoor UVB through smart device and mobile application. When a user is indoors, the LED controller and lighting control application control the UVB-LED lighting after estimating the UVB-LED lighting service duration to synthesize the required amount of vitamin D through a comparison of the vitamin D amount met indoors and outdoors with the daily target amount of vitamin D. Afterwards, simulation was conducted to evaluate daily synthesis of vitamin D using a UVB-LED lighting system. The results indicate that people that spend a lot of time indoors can use a UVB-LED lighting service to synthesize vitamin D according to seasonal characteristics, type of outdoor activities, and time spent outside.*

***Index Terms:** UVB, Vitamin D, UVB-LED, LED Lighting Control System, UVB-LED lighting service*

I. INTRODUCTION

Vitamin D is an essential factor in shaping a human's musculoskeletal system. Vitamin D synthesis within a human body by dietary intake takes up 10%, whereas the UV exposure effect is known to account for 90% [1]. UV, which is a shorter wavelength band than visible light (VIS) in the solar light spectrum, is classified into UVC (100-280nm), UVB (280-315nm), and UVA (315-400nm). Each domain of UV differs in the extent of arriving at the surface of the earth according to ozone layer absorption. The UVC domain is almost completely absorbed by the ozone layer, but the UVA and UVB domains take up 90-99% and 1-10% of the UV arriving at the surface, respectively [2]. UV in the UVA and UVB domains is used when UV is exposed to the human body for medical use and beauty care. The UVB amount of natural light becomes different according to geographical location and season. According to Holick MF [3] in 2004, vitamin D amount generated by skin synthesis remarkably declines in winter, compared to summer, due to an increase in UVB absorbed by the ozone layer.

Interest in skin whitening has increased recently, owing to preference for white skin, while negative effects revealed by excessive exposure to UV are emphasized. Therefore the duration of exposure to UV has decreased due to excessive use of UV cream and certain types of clothes. The duration of staying indoors among modern people has increased due to habit change in everyday life, with the duration of exposure to UV gradually diminishing [4]. Especially modern people spend an average of 85%~90% of their per day indoors [5]. Therefore, there is a need of research for developing general lighting that can safely provide UVB light quantity essential for human health to people who are rarely exposed to natural light. In 2011, Choi HS [6] reported that the ratios of Korean males and females belonging to the abnormal range of vitamin D level within the body took up 86.6% and 93.3%, respectively, according to the results of the NHANES(National Health and Nutrition Examination Survey). Among them, it was reported that 47.3% and 64.5% of males and females were deficient and extremely deficient of vitamin D, respectively. As a result of vitamin D level analysis according to physical activity, residential area, and occupational group, it was identified that the blood concentration of vitamin D was higher in those who have more physical activity outdoors, those who reside in agricultural and fishery areas instead of urban areas, and those who belong to the agricultural and fishery occupation groups than in the office work or service industry groups [4].

The phenomenon of vitamin D deficiency not only deteriorates musculoskeletal health, but can cause various diseases such as metabolic syndrome, diabetes, and depression [3]. A variety of studies have been recently carried out domestically and internationally in order to solve vitamin D deficiency by categorizing it into "normal" and "deficient" depending on the blood concentration of vitamin D and by presenting daily minimum/maximum recommended amount of vitamin D [7-9, 23-30]. In 2014, Ming Cheuk et al. [10] developed a smartphone-based personal UV information offering service tracking vitamin D amount generated according to daily UV cumulative capacity by combining wearable device and UV sensor data and recommending action policy depending on current UV level. As such, studies to acquire favorable part of UV to be

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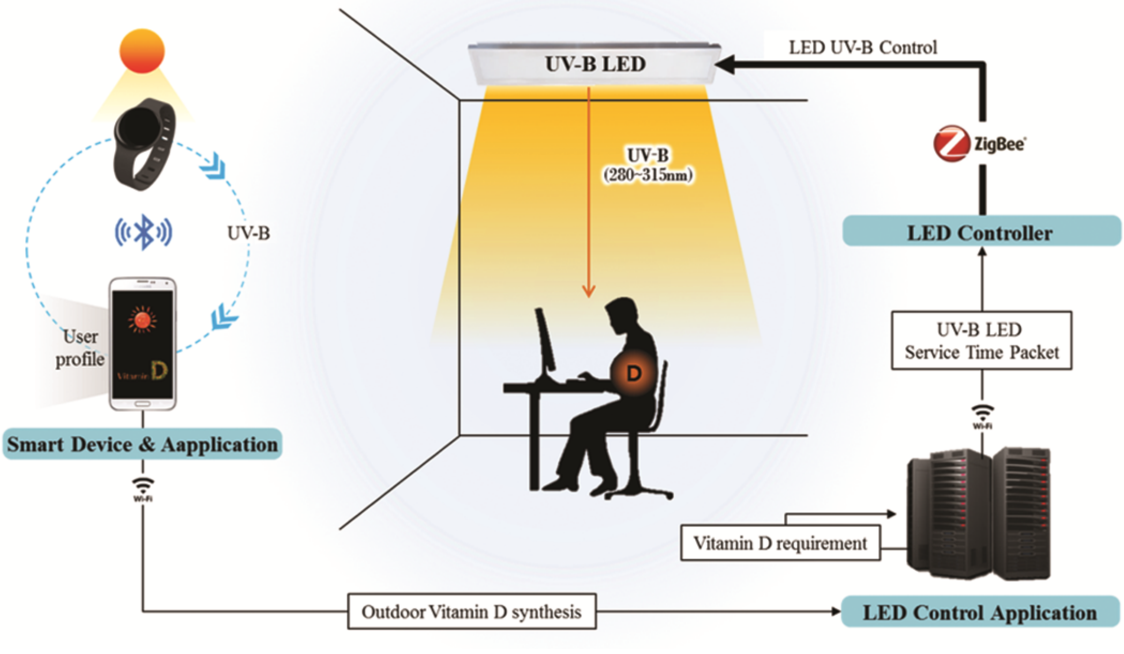

Figure 1. UV-B LED lighting system's conceptual diagram

safely exposed are being conducted.

As modern people stay indoors for a long time, interest in the indoor lighting environment rises, and studies on the indoor LED lighting system are actively carried out. As it is presented that light is closely associated with human's circadian rhythm control, researches on LED control algorithm taking into accounting human's life pattern, as well as artificial light source development to reproduce light similar to natural light through the lighting environment, are conducted. Kim et al. [11] developed a system by which indoor lighting's color temperature can be controlled through a control application in which Bluetooth wireless communications are possible by properly changing color temperature from the indoor lighting environment so that the comfortable environment can be shaped, not to mention a pleasant resting environment. Ji-seon Ryn et al. [12,23-27] released an analysis result that illuminance change in the lighting environment affects a human's physiological and psychological responses. Jung-Soon Yang [13] presented the control data of circadian lighting similar to natural light in each time slot through a comparative analysis on the colors of natural light and LED lighting through the actual measurement of natural light.

This study suggests a UVB-LED lighting system that can meet the daily target amount of vitamin D through daily offered UVB amount that is required in the state where an occupant staying indoors for a long time does not perceive. The system suggested in this study controls the UVB irradiance of LED lighting in order to synthesize lacking vitamin D amount, after comparing the synthesized vitamin amount indoors and outdoors and the daily target amount of vitamin D based on each season's UVB irradiance analysis of natural light and occupant's profile (daily target amount of vitamin D, skin type, and exposure area).

II. UVB-LED LIGHTING SYSTEM DESIGN

The suggested system can synthesize vitamin D, while existing indoor illuminance can be maintained. For an occupant who finds it difficult to meet the required vitamin D through the UVB of natural light due to the lack of outdoor activity, UVB light source was additionally deployed to indoor LED lighting. Figure 1 shows the UVB-LED lighting system's conceptual diagram.

Smart devices and applications can conduct UVB irradiance sensing and calculate the synthetic amount of vitamin D by indoor and outdoor activities. Smart devices and applications can conduct UVB irradiance sensing and calculate the synthetic amount of vitamin D by indoor and outdoor activities. In addition, IOT smart devices provide environmental information of temperature and humidity. The lighting control application was designed to compute the UVB-LED lighting control duration needed to meet the daily target amount of vitamin D, based on the synthetic amount of vitamin D, when an occupant enters indoors.

Figure 2 shows the block diagram of the UVB-LED lighting system suggested in this study. The system consists of smart device, mobile application, lighting control application, and UVB-LED lighting.

A. Database composition to extract lighting control indicators

The synthetic amount of vitamin D in the skin through exposure to UVB is affected by UVB irradiance,

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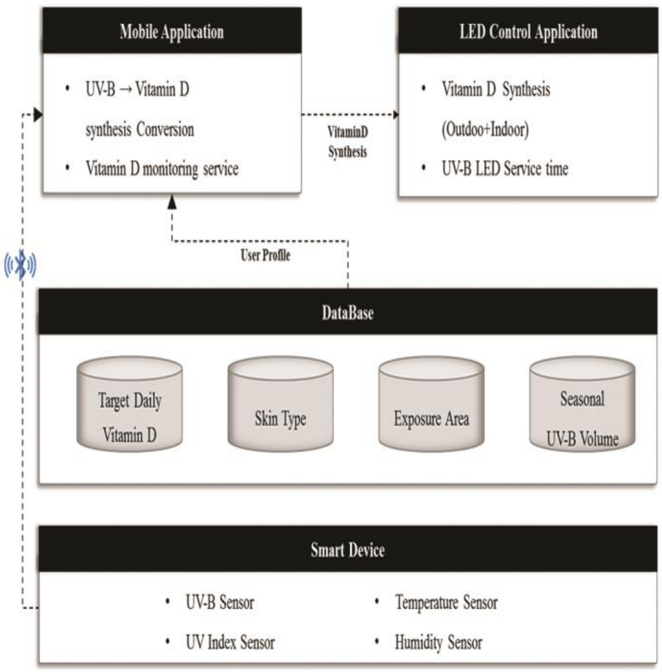

Figure 2. Block diagram of the UVB-LED lighting system

Table 2. Seasonal UVB and UV indexes

Season	Month	outdoor activity duration					
		Morning(08:30-09:00)		Noon(12:00-12:30)		Afternoon(18:00-18:30)	
		UVB	UV Index	UVB	UV Index	UVB	UV Index
Spring	Mar	0.041	0.75	0.269	4.29	0.003	0.08
	Apr	0.071	1.2	0.314	4.9	0.010	0.2
	May	0.133	2.18	0.478	7.39	0.020	0.39
Summer	Jun	0.118	1.93	0.473	7.29	0.027	0.5
	Jul	0.111	1.8	0.438	6.71	0.028	0.5
	Aug	0.093	1.55	0.438	6.74	0.019	0.36
Fall	Sep	0.088	1.48	0.382	5.92	0.006	0.13
	Oct	0.042	0.74	0.265	4.16	0.001	0.0083
	Nov	0.015	0.27	0.113	1.82	-	-
Winter	Dec	0.006	0.13	0.095	1.58	-	-
	Jan	0.005	0.12	0.113	1.87	-	-
	Feb	0.010	0.21	0.143	2.37	0.001	0.02

skin color exposed to UV, and exposure area according to geographic location and seasonal characteristics.

1) Daily Target Amount of Vitamin D

Table 1. Adult occupant's daily recommended amount of vitamin D reported at home and abroad

Institute	Recommended Amount		
	Minimum	Enough	Maximum
The Korean Society of Osteoporosis (2008)		800IU	1000IU
The Journal of Clinical Endocrinology and Metabolism (2011)	600IU		4000IU
MINISTRY OF HEALTH AND WELFARE and THE KOREAN NUTRITION SOCIETY (2015)		400IU	4000IU

Although vitamin D's functions to human body are known to be similar according to age, the effects of vitamin D to human body by age are different. Adults need to take in adequate calcium and vitamin D to maintain skeletal strength and prevent osteomalacia and osteoporosis. Table 1 shows an office space adult occupant's daily recommended amount of vitamin D reported at home and abroad [7-9]. The daily target amount of vitamin D for an office space occupant is set to 400 IU as reported by the Ministry of Health & Welfare and the Korean Nutrition Society in 2015, while the maximum target amount is defined as 4000 IU.

2) UVB Irradiance According to Seasonal Characteristics

Seasonal UV patterns were analyzed using UV data observed at Anmyeondo Island in 2015 as offered by the Korea Meteorological Administration among six currently operated points in Korea (Pohang, Mokpo, Anmyeondo Island, Jeju, Gosan, and Ulreungdo Island) [14]. Table 2 shows seasonal UVB (MED/10 min) and UV indexes. Because indoor activities are recommended, the days when the UV index was 8 or higher were excluded in the calculation of UVB irradiance [15]. Seasonal classification was conducted as follows: spring (March-May), summer (June-August), fall (September-November), and winter (December-February).

According to the mean UVB irradiance and UV index during the outdoor activities by season, UVB irradiance in spring showed a difference of 22 times from that in summer and winter. From the differences in the synthetic amount of vitamin D by season, it can be inferred that uniform UV amount is difficult to be offered all-year-round due to Korea's location. In the summer when the sun's altitude is high, vitamin D can be synthesized sufficiently through much irradiance of UV amount. However, the lack of vitamin D is caused in winter because the UV amount becomes small, and also the skin part exposed to UV decreases, owing to wearing clothes in order to keep the body warm.

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3) Skin Type

The difference in melanin cell determines the skin color of humans. The melanin cell is one of the cells constituting human skin, and it was made to prevent UV from penetrating the skin deeply by absorbing UV or to protect the skin from external stimulating factors. Table 3 shows the responses of

six skin types, by stars and sun, divided by the Fitzpatrick scale [16] in 1988 and minimum erythermal dose (MED). Types III, IV, and V took up 48.8%, 22.2%, and 17.8%, respectively, in terms of Koreans' skin types, namely III-V types accounting for 88.8% [17]. Therefore, type III showing the most distribution is defined as an occupant's skin type.

Table 3. Fitzpatrick scale

Type	Skin color	MED, J/m^2	Sun-Reactive
I	White or very pale	200	Always burns, never tans
II	Pale white with beige tint	250	Always burns, easily tans minimally
III	Beige to light brown (olive)	300	Burns moderately, tans uniformly
IV	Light to moderate brown	450	Burns minimally, always tans well
V	Medium to dark brown	600	Rarely burns, tans profusely
VI	Dark brown to black	1000	Never burns

4) Exposed Area

The exposed area in human body is called body surface area. Seasonal exposed area is different in Korea, which has distinctive seasonal characteristics, due to people wearing various types of clothes according to season. Given that Korean's mean UV sensitivity is similar to or slightly lower than that of white people, it was reported that human body can synthesize 400 IU vitamin D, when 6-10% of body surface area is exposed to 1 MED [18].

Table 4 shows body surface area ratio by human part based on Korean adults [19]. The occupant's exposure area is set to 25% in summer when the face, neck, hand, and arm are exposed, and to 10% in spring, fall, and winter when the face, neck, and hand are exposed, in consideration of wearing various types of clothes according to season.

Table 4. Body surface area ratio

Human part	Body surface area ratio	Detail part(area ratio)
Head	7.8 %	Head (7.8 %)
Neck	1.3 %	Neck (1.3 %)
Trunk	37.7 %	Trunk (37.7 %)
Arm	15.1 %	Right upper arm (4.4 %)
		Right forearm (3.1 %)
		Left upper arm (4.5 %)
		Left forearm (3.1 %)
Hand	5.0 %	Right hand (2.5 %)
		Left hand (2.5 %)
Leg	26.3 %	Right thigh and calf (13.1 %)
		Left thigh and calf (13.2 %)
Foot	6.7 %	Right upper foot (2.5 %)
		The sole of the right foot (0.9 %)
		Left upper foot (2.5 %)
		The sole of the left foot (0.9 %)

B. Smart Device and Mobile Application

Smart devices are to sense UVB exposure amount during outdoor activities, and they consist of a UVB sensor, UV index sensor, and temperature/humidity sensor. Sensing data are transmitted and received through Bluetooth Low Energy (BLE) communications with a mobile application. Table 5 shows the sensor modules and functions of the smart devices, and Figure 3 reveals the communications protocol.

Table 5. Sensor modules and functions of the smart devices

Sensor Module	Model	Specifications and Features
MCU	Arduino NANO	ATmege328 Micro Controller Unit (MCU)
Bluetooth Module	HBT2X3N	Android / iPhone serial communication support
UVB Sensor	GUVB-T1CFD	Wavelength measurement in the range of 275-320 nm
UVI Sensor	TOCON_E2	Total UV Index Measurement
Temp·Hum Sensor	DHT11	Temperature (0-50° C), Humidity (20-90%) Measurement
Display Module	12864 OLED LCD	Supports Serial Peripheral Interface (SPI) communication
Charging and Battery Module	JBATT-U5-LC and C51021RB	Power supply (rechargeable) and lithium polymer battery (550mAh)

Figure 3 shows the communication protocol between smart devices and mobile applications. One to multi-type BLE communications are possible, and the advertise mode by which data can be regularly sent was designed. The communications protocol consists of header and data. The header includes a preamble field synchronizing frequency from a packet's receiver, an access address field testing a packet's effectiveness, and a CRC field carrying out circulation duplicate inspection for error detection. Data consist of an MAC address field to identify devices, and

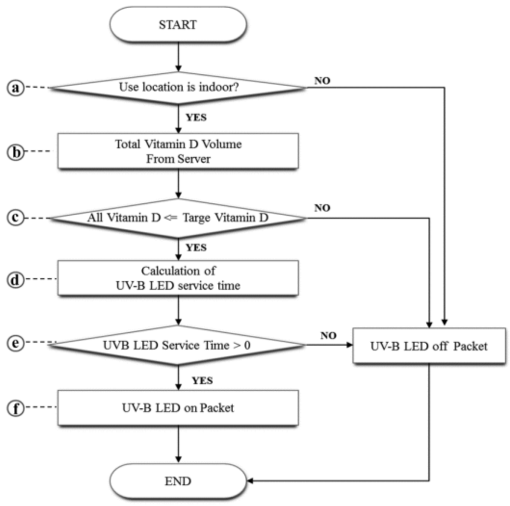
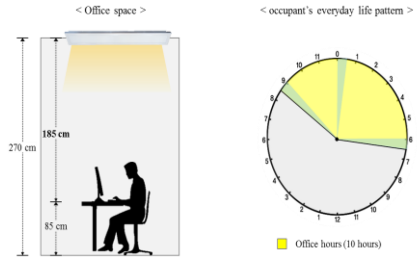


Figure 5 Flowchart of UVB-LED lighting control of

advertising including UVB and UV indexes, and temperature and humidity data.



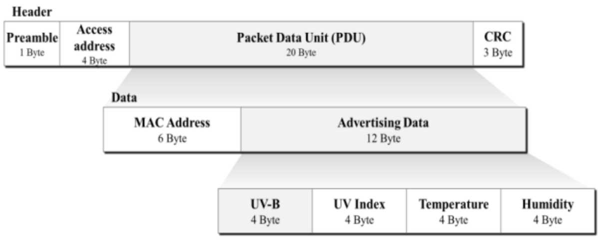


Figure 3.BLE protocol

The mobile application computes the synthetic amount of vitamin D based on UVB sensing data received from the devices and occupant's personal profile. EUV(Erythemal weighted UV radiation) is used by applying an erythemal weighting function by wavelength to erythemal ultraviolet (EUV) in calculating the synthetic amount of vitamin D through exposure to UV. Equation 1 is the formula to calculate the synthetic amount of vitamin D[20].

$$Vitamin\,D = \frac{EUV[W/m^2] \times Etime[s]}{MED[J/m^2]} \times Earea[\%] \times 40IU$$

(1)

• Erythema UV radiation (EUV): Erythema UV radiation
• Minimum Erythema Dose (MED): MED of skin type
• Exposure time (Etime): Exposure time
• Exposure area (Earea): Exposure area

Figure 4 shows the flowchart for the computation of a synthetic amount of vitamin D. The synthetic amount of vitamin D is as follows:

ⓐ Received UVB sensing data from a smart device
ⓑ Received personal profile from the occupant (e.g., occupant's age, skin type, daily recommended amount of vitamin D)
ⓒ Set body exposure area according to current season
ⓓ Calculated synthetic amount of vitamin D based on UVB sensing dat a and personal profile using Equation 1
ⓕ Transmitting to the LED controller is done by generating the transmission packet for lighting control including the service duration of UVB-LED.

.UVB-LED Lighting Control Service

The lighting control application calculates the UVB irradiance amount required to meet the daily recommended amount of vitamin D by comparing the synthetic amount of vitamin D synthesized indoors and outdoors and the daily recommended amount of vitamin D. After computing the lighting service duration based on the hourly UVB irradiance of the UVB-LED lighting, the lighting control packet including the duration of UVB lighting control is generated, and UVB-LED is controlled through an LED controller that can conduct ZigBee wireless communications. Figure 5 shows the flowchart of UVB-LED lighting control of the lighting control application.

The UVB-LED lighting control procedure to meet the daily recommended amount of vitamin D of an occupant is presented below:

ⓐ The lighting control application checks whether the user (smart device and application) is indoors.
ⓑ If the user is indoors, the received synthetic amount of vitamin D is synthesized through exposure to UVB.
ⓒ After computing the daily synthetic amount of vitamin D, it is compared with the daily recommended amount of vitamin D.
ⓓ The UVB-LED lighting service duration required to meet the target amount is computed.
ⓔ Whether UVB-LED lighting service needs preparation time is checked.

SIMULATION TO EVALUATE VITAMIN D SYNTHESIS

C. UVB-LED Lighting Service Environment

The UVB-LED lighting service targets occupants sitting in the indoor office space. Figure 6 defines the office space and occupant's life pattern as the service environment. The heights of the ceiling and working surface were set up as 270cm and 85cm, respectively, and the distance between the ceiling lighting and the occupant was set up as 185cm [21-22]. The UVB lighting service duration in the office space was set up as 10 hours in total between 08:30 and 18:30.

The UVB light source was additionally placed to existing VIS lighting in terms of UVB-LED lighting. An occupant in the office space can meet the daily target amount of vitamin D despite the absence of outdoor activity. Erythema should not develop by exposure to UVB, so this study calculated the maximum erythemal UV radiation amount by applying an occupant's skin type, exposure area, and maximum lighting use duration [19]. Table 6 shows the result of maximum erythemal UV radiation amount calculation.

This study made the total amount of UVB generated from the UVB-LED lighting exceed 3.3 mW/m2 (minimum) to 8.3 mW/m2 (maximum) according to exposure area. In this regard, the amount of vitamin D synthesized using UVB-LED lighting is equal to 40 IU per hour.

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E. Simulation results and analysis

The UVB-LED lighting use duration of an occupant to meet the daily target amount of vitamin D—400 IU—needs to exclude the synthesized amount of vitamin D outdoors. Even in the case of outdoor activity for 2 hours equally, the synthesized amount of vitamin is different because of a different UVB irradiance in a season. Specifically, the lighting use duration to meet the daily target amount of vitamin D is different according to season. Table 7 shows the synthetic amount of vitamin D, as well as the required UVB-LED lighting service duration by outdoor activity with the same outdoor activity duration.

Table 6. Maximum Erythemal UV Radiation Amount

Synthesized amount	Skin type	Exposure duration	Exposure area	EUV
400 IU	300 J/m^2	10 hour	25 %	3.3 mW/m^2
			10 %	8.3 mW/m^2

To meet the target amount of vitamin D, 1 hour and 9 minutes, 4 hours and 25 minutes, and 8 hours and 50 minutes were required in spring, fall, and winter, respectively. In summer, the daily target amount of vitamin D could be met with only two hours of outdoor activity, and thus UVB-LED lighting was not needed.

The office space occupants' activity type was defined as 8 types, and the required UVB-LED lighting service duration by season was computed. The occupants' activity type was divided into eight types during the morning, noon, and afternoon. Table 8 shows the occupants' outdoor activity types and activity duration.

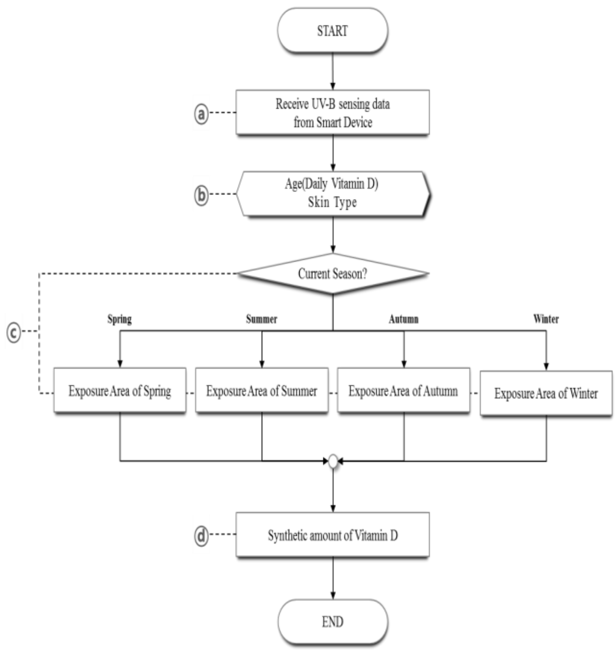

Figure 4. Flowchart for the computation of synthetic amount of vitamin D

Table 7. Synthetic Amount of UVB-LED and Required UVB-LED Ligl

Classification		Spring
Occupant	Daily target amount of vitamin D	**400 IU**
	Outdoor activity duration	2 hours
	Synthetic amount of vitamin D	354 IU
	Deficient vitamin D amount	46 IU
	Duration requiring UVB-LED lighting	1 h and 9 min

Table 8. Occupants' Outdoor Activity Type and Duration

●: outdoor activity

CASE	Morning (08:30-09:00)	Noon (12:00-12:30)	Afternoon (18:00-18:30)	Total Outdoor activity
CASE 1	-	-	-	-
CASE 2	●	-	-	30 min
CASE 3	-	●		30 min
CASE 4	-	-	●	30 min
CASE 5	●	●	-	1 h
CASE 6	-	●	●	1 h
CASE 7	●	-	●	1 h
CASE 8	●	●	●	1h and 30 min

To calculate the required UVB-LED lighting service duration by season, Table 8 was used regarding occupants' outdoor activity type and duration. The outdoor UVB irradiance is different according to season, and the required duration of UVB-LED lighting service is different even in the same activity type and duration. The required UVB-LED lighting service duration was computed after calculating the vitamin D amount by deducting the synthetic amount of vitamin D through outdoor activity from the daily target amount of vitamin D, 400 IU. Table 9 shows the required UVB-LED lighting service duration by season reflecting occupants' outdoor activity type and duration and seasonal characteristics.

Table 9. Required UVB- LED Lighting Service Duration by Season

CASE	Outdoor					Indoor			
	Duration (hh:mm)	Synthetic amount of vitamin D (IU)				Required UVB-LED lighting service duration (hh:mm)			
		Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
CASE 1	**0:00**	0	0	0	0	10:00	10:00	10:00	10:00
CASE 2	**0:30**	69	226	40	6	8:17	4:21	8:59	9:51
CASE 3	**0:30**	266	697	206	99	3:20	**0:00**	4:51	7:32
CASE 4	**0:30**	9	52	2	0	9:45	8:42	9:57	**10:00**
CASE 5	**1:00**	335	923	246	104	1:38	**0:00**	3:50	7:23
CASE 6	**1:00**	275	749	208	99	3:06	**0:00**	4:48	7:31
CASE 7	**1:00**	78	277	42	6	8:03	3:04	8:56	9:50
CASE 8	**1:30**	344	975	248	105	1:24	**0:00**	3:47	7:23

In case 1, the daily target amount of vitamin D can be fully met with only 10 hours in UVB-LED lighting. In summer, the daily target amount of vitamin D was met with 30 minutes in outdoor activity at noon in cases 3, 5, 6, and 8, and therefore no UVB-LED lighting was needed. Meanwhile, the synthetic amount of vitamin D was 52 IU with outdoor activity at sunset, and thus 8 hours and 42 minutes in UVB-LED lighting service was required. In the event of case

8 in which 1 hour and 30 minutes in outdoor activity were conducted, UVB-LED lighting was not needed in summer, but UVB-LED lighting service duration between 1 hour and 7 hours was required in spring, fall, and winter.

III. CONCLUSION

Vitamin D is activated by dietary intake and skin synthesis by exposure to UV, and plays a pivotal role in maintaining human health. UVB among UV domains causes various skin diseases upon excessive exposure to UVB of the human body, although UVB is effective in generating vitamin D within the human body if adequate amount is received. Today, modern people's UV exposure duration rapidly decreases due to UV cream, certain clothes, and increase in duration of staying indoors. This study suggests a UVB-LED lighting system for a user exposed to vitamin D deficiency due to staying indoors for a long time to meet the daily target amount of vitamin D.

The suggested UVB-LED lighting system consists of smart devices and a mobile application for UVB irradiance, sensing outdoor natural light and synthetic amount of vitamin D computation, an LED controller for lighting control, and a lighting control application. The smart devices conduct sensing outdoor UVB irradiance and transmit it to a mobile application through BLE communications. The mobile application computes the synthetic amount of vitamin D by applying UVB irradiance and an occupant's personal profile. When a user is indoors, the lighting control application receives the data for synthetic amount of vitamin D during the outdoor activities. The application computes UVB-LED lighting control duration to synthesize vitamin D amount required to meet the daily target amount of vitamin D by comparing the total vitamin D amount synthesized indoors and outdoors and the daily target amount of vitamin D, creates transmission control packet for lighting control, and controls UVB-LED through the LED controller.

A simulation was conducted to evaluate whether vitamin D synthesis can be supported with the suggested system. This simulation sets an adult's daily target amount of vitamin D to 400 IU, exposed area to 25% in summer and 10% in spring, fall, and winter, with skin type III accounting for most of the control data of Korea's occupant personal profile. As for UVB-LED lighting service environment, the distance between lighting and occupant was set to 185cm, and occupant's lighting use duration to 10 hours maximum. UVB light source was designed to be deployed additionally to existing general illumination in order to absorb 400 IU, the daily recommended amount of vitamin D for 10 hours and the maximum lighting use duration.

UVB-LED lighting use duration was controlled for the occupants to generate a daily target amount of vitamin D, 400 IU, when combined with vitamin D synthesized during outdoor activity. The daily target amount of vitamin D could be met with only UVB-LED lighting in all seasons without outdoor activity as a result of the experiment and analysis of UVB-LED lighting system reflecting outdoor activity type and duration and seasonal characteristics. In summer, the daily target amount of vitamin D could be met with just 30 minutes of outdoor activity at noon. However, the target amount could not be met with only outdoor activity at sunset, and therefore 8 hours and 42 minutes in UVB-LED lighting service were needed. UVB-LED lighting from 1 hour to 7 hours was used in spring, fall, and winter according to seasonal characteristics, even in the case of outdoor activity for 1 hour and 30minuts during the day. As a result, it was found that modern people living indoors can meet daily vitamin D synthesis targets when UVB-LED lighting system is utilized according to their seasonal characteristics, type of outdoor activities, and time spent outside.

The system in this study is expected to be actively used to prevent vitamin D deficiency through application to the indoor spaces where occupants stay for a long time including home and residential and public spaces, as well as indoor office spaces. Having said that, a further study to add a dimming function that can variable control the UVB irradiance of UVB-LED is needed. Furthermore, according to dimming lighting tests for IEC62471 will be conducted.

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