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THE BEHAVIOR OF INTERNAL HUMIDITY FROM FIBRE OPTIC DAYLIGHTING SYSTEM APPLICATION

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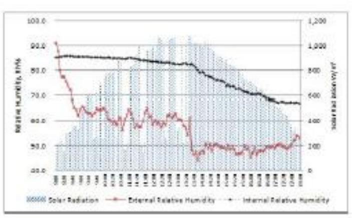
Graphical abstract



Abstract

Electrical lighting consumed 13% to 43% from overall energy which considered as second major usage of electrical energy in a building. Fibre optic daylighting is a potential approach for the remote source daylighting which is able to minimize the usage of electrical light if the minimum recommended standard of human comfort is achieved. Since the internal humidity also plays an important role in human comfort, the objectives of this research are to investigate the effects of the application inside building for humidity. This research assessed the potential of fibre optic daylighting for interior illumination using 4 m x 5 m x 2.8 (H-Ceiling) spaces through empirical data collection in an actual environment. The data were collected for every 5 minutes from 8:00 AM to 6:00 PM on the 17th May 2013 until the 2nd June 2013 using 4 computer-linked sensors to record humidity for both external and internal building. The comparison approach was selected in analyzing the data collected with the observation. . It is shown that the fibre optic daylighting system has no significant effect in relative humidity even possibly increases the internal room temperature by 2°C.

Keywords: Remote-source daylighting, fibre optic daylighting, internal humidity

Abstrak

Lampu elektrik mewakili 13% hingga 43% jumlah tenaga merupakan punca kedua terbesar penggunaan elektrik dalam bangunan. Gentian optik ialah pilihan wajar untuk pencahayaan siang jarak jauh dalam mengurangkan penggunaan lampu elektrik jika standard minima keselesaan manusia tercapai. Memandangkan kelembapan dalaman memainkan peranan penting dalam keselesaan manusia, objektif kajian ini untuk menguji kesan terhadap kelembapan. Kajian ini mengujikaji potensi cahaya-siang gentian optik menggunakan ruang 4 m x 5 m x 2.8 m (T-Siling) melalui kutipan data impirikal dengan persekitaran sebenar. Data direkod setiap 5 minit dari jam 8:00 AM ke 6:00 PM pada 17 Mei 2013 hingga 2 Jun 2013 menggunakan 4 pengesan terangkai-komputer untuk merekod kelembapan relatif luar dan dalam bangunan. Kaedah perbandingan diguna pakai dalam analisis dengan pemerhatian. Ditunjukkan bahawa pencahayaan siang gentian optik tidak memberi kesan pada kelembapan tetapi dapat meningkatkan suhu dalaman bilik sehingga 2°C.

Kata kunci: Cahaya siang-jauh, cahaya siang gentian optik, kelembapan dalaman

1.0 INTRODUCTION

Natural light technology has made some notable strides recently, providing higher quality lighting at reduced cost. Daylighting is not expensive anymore to be implemented as compared to traditional lighting solutions. If an integrated design approach is used, daylighting quickly produces attractive paybacks. Energy studies in Malaysia conclude that electrical lighting represents up to 30% of building electricity consumption in a commercial office building [1, 2] meanwhile [3] concluded that lighting consumption in Malaysia's residential buildings is 25.3%, shopping complexes 51.9% and offices 42.5% respectively.

Malaysia's climate is blessed with a constant reliable sun rays and sources quite fairly distributed between day and night in twelve-hour alternation. This source has been ignored as a main source for lighting distribution in building until recent years where scholars and researchers implemented applied science and awareness in energy matter based on application that have been studied and established in the developed country. Optimizing the fibre optic daylighting configuration to integrate both available solar sources outside building by bringing it inside can minimize the usage of artificial light but the minimum recommended standard must be achieved.

Above statements however need to be proved by reliable empirical results that will be explicated in this research which consider overall investigation to assess the actual performance of the fibre optic daylighting system employing the optimum approach which is tested and evaluated under real tropical skies.

Therefore, a remote source fibre optic daylighting approach for interior illumination is significant to be explored by this research, expected to meet minimum standard of Green Building Index (GBI) and MS1525:2007 Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings (First Revision) under interior lighting's subtopic.

The evaluation of the optimum approach in fibre optic daylighting system is to understand the overall potential and to investigate the effects on relative humidity from the system approach.

Next is to translate the optimization of experiment to a full-scale experiment conducted in a 5 m x 4 m x 2.8 m (H-Ceiling) test-bed. This test-bed is a typical standard working room constructed at the School of Housing, Building and Planning, Universiti Sains Malaysia Pulau Pinang.

Various parameters were recorded in support of the research objectives and research questions. The parameters involved are external and internal illuminance level, external and internal temperatures, external and internal humidity, external solar radiation and surface temperatures for lighting diffuser and ceiling board.

This full-scale field study however will only consider the installation of full range fibre optic daylighting system using solar receiver, fibre optic cable and light diffusing fitting system to meet the objectives of research. The selection for the optimum approach of fibre optic daylighting system is made based on the literature reading suggested by previous researchers. This research presents empirical findings on the assessment of daylighting system using fibre optic cable for interior illumination in Malaysia skies. The optimum approach of fibre optic daylighting system was obtained from Parans Sweden consisting of latest 3rd generation set SP3 receiver, 6 numbers of 10 meters fibre optic cables and 6 numbers of L1 type diffusers. Parans was selected due to its patented technology since 2002 and their first product was commercialized in 2004 which was developed through extensive Research and Development in collaboration with Chalmers Technical University in Gothenburg, Sweden [4].

The research test bed was constructed using commonly found building materials at the School of Housing, Building and Planning, Universiti Sains Malaysia Pulau Pinang, Malaysia. The full scale field study data collected made by using a computer program linked with sensors to store the parameters in 5 minutes intervals for a period of 17 days starting from 17th May 2013 until 2nd June 2013. The research parameters are limited to external and internal humidity, external solar radiation and surface temperatures for lighting diffuser and ceiling board. Any other possible effects due to this exercise such as indoor air quality, acoustic comfort as also mentioned in MS1525:2007 will not be covered in this research. The perception estimating in cloud cover category is used. It is determined by using either Nebulosity Index, Oktas calculation or IESNA Classification is only a guideline but it has not been applied in this research.

2.0 DESIGN PARAMETER

The GBI is an environmental rating system for buildings developed by PAM (Pertubuhan Arkitek Malaysia) (http://www.pam.org.my) and The Association of Consulting Engineers Malaysia (http://www.acem.com.my) following Malaysian Standard 1525:2007 [5]. The GBI is Malaysia's first comprehensive rating system for evaluating the environmental design and performance of Malaysian buildings based on six (6) main criteria. The GBI is developed specifically for the Malaysian tropical weather, environmental and developmental context, cultural and social needs. GBI Malaysia is currently promoted and recommended through research and experiments mainly in energy efficiency for buildings in Malaysia. Based on the studies made, we can conclude that the recommended values based on the parameter stated in GBI Malaysia are as mention in Table 1.

Table 1 Recommended internal parameters by GBI Malaysia

PARAMETERS	RECOMMENDED VALUES
Minimum Dry Bulb Temperature	22°C
Design Dry Bulb Temperature	23°C - 26°C
Humidity: Design Relative Humidity	55% - 70%
Air Movement	0.15m/s - 0.5m/s
Max Air Movement	0.7 m/s

Source: [6]

Malaysian Standard, in MS 1525:2007 earlier outlined the recommended value for internal parameters as shown in Table 2.

Table 2 Recommended internal parameters by MS1525

PARAMETERS	RECOMMENDED VALUES
TEMPERATURE : Dry Bulb Temperature	23 °C – 26 °C
HUMIDITY: Design Relative Humidity	55 % - 70 % ; A space relative humidity below 70 % for comfort cooling purposes.
Height of Measurement Light Source	800 mm above the floor level

Source: [5]

Comfort temperature is 24°C and relative humidity is between 55% to 70%. The values become a design standard in Malaysia and will be a benchmark in summarizing the outcome from this research.

2.1 Relative Humidity

In most parts in Malaysia, the average of Relative Humidity (RH) level is almost uniformly high at about 70%-90% throughout the year, reaching the most critical values of 99% during the night and Monsoon seasons [7]. However, the lowest values of relative humidity during the day take place between 1.00 PM and 5.00 PM, which corresponds to the peaks of outdoor air temperature. This is due to the fact that the higher temperature, the higher the amount of moisture (humidity in steam form) that air can hold, which in turn makes the percentage values of relative humidity decrease at the same time that the air temperature increases.

2.2 Methods of Directing External Illuminance to Building Interiors

Many studies on different methods of bringing external illuminance to building interiors were done by previous researchers and some of them can be listed below. Table 3 summarized the research related to the method in bringing daylighting into the building from 1997 to 2012.

This research focus on the interior space daylighting by using fibre optic cable as a part of active daylighting to investigate the internal humidity effects.

2.3 Fibre Optic Daylighting

Fibre optic is an elastic, crystal clear material made of very pure glass (normally silica) that plays as a tunnel to transmit light between one ends to another.

A fibre optic is a cylindrical dielectric waveguide that channelize light along its axis by the procedure of total interior reflection. The fibre comprises of a core bordered by a protective cover layer, both of which are made of dielectric materials [18].

Fibre optic typically consists of a crystal clear core bordered by reflective sheath material with a lower refractive index. Light is travelled in the core by total internal reflection with extremely low loss. In current application, fibre optic is possible to be used as the remote sunlight path from the external building to other parts of the building as a lighting system. [19, 18, 10].

Fibre optic daylighting system is a developing technology that will provide a resolution for daylighting designers. This systems use fibre optics with solar light collectors to transmit daylight to spaces previously difficult to daylight using side lighting or top lighting strategies. Fibre optic light transmission systems include a collector, reflectors, filters, lenses to direct light to the fibre optic cables, and a diffuser to distribute the light in the area to be illuminated. The term "remote source lighting" has been used to describe this type of system that conveys light to a destination not directly accessed by the light source [20]. Table 4 shows a list of studies that had been made by previous researchers in evaluating fibre optic cable for interior illumination lighting in various places.

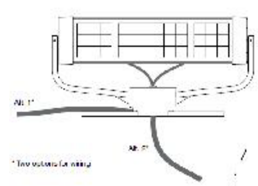
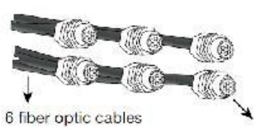
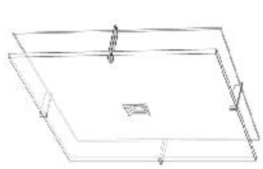
Table 3 Summary of previous researches related to methods of bringing external illuminance into the building

No	Researchers/Area	Solar Tube	Light Shelf	Skylight	Light well	Atria	Fibre Optic
1	O'Connor *et al*. (1997) U.S [8].		■				
2	A.Zain (2000) Malaysia [9].						
3	Grise and Patrick (2002) U.S [10].						■
4	Garcia-Hansen and Edmonds (2003), Aus [11].	■					■
5	Krarti *et al*. (2005) U.S [12].						
6	Kroelinger (2005) U.S [13].		■	■	■	■	
7	Han and Kim (2009) Korea [14].						■
8	Chiras (2011), UK. [15].	■					■
9	Seied *et al*. (2011), Sudan [16].						
10	Wong and Yang (2012), Hong Kong [17].						■

2.4 Optimized Fibre Optic Daylighting System

The final configuration for optimum approach of fibre optic daylighting system was made earlier based on the justification explained. Basically, the fibre optic daylighting system has 3 major components as highlighted by [10, 11, 22, 24, 26, 27] as summarized in Table 4. This research considers a Fresnel lenses type of solar receiver with sun tracking system as it was also selected by [29, 22, 23, 30] in their researches. Fresnel lens is widely used because it gives the good performance at a low cost [26].

Table 4 The selected optimum approach of fibre optic daylighting system

Main Components and Description

<u>Receiver (Fresnel Lens):</u> The receiver follows the sun over the day to collect its light. Optical design is using lenses to capture and concentrate the optimal amount of sunlight into the fibre optic cable for immediate transfer into the building. The receiver is powered up with a 10 W adapter for its motor and electronic sun tracking circuit inside the receiver.

<u>Fibre Optic Cable (10 meters):</u> Six solar fibre optic cables are attached together at 10m length from the receiver to inside building. The cables have very good ability to transport light while retaining the full spectrum of the light. Cables are thin, flexible, and made of high pure silica which is common in fibre optic daylighting system.

<u>Diffusers:</u> The diffusers are connected to the end of the fibre optic cables and will diffuse the light that had been concentrated earlier into the building spaces.

Source: [4].

3.0 RESEARCH METHODOLOGY

3.1 External Data Collection

Since this research is aiming at the comparison study related to external and internal condition, the mini meteorological station was installed outside the building to record external parameters involving solar radiation, relative humidity and external air temperature. The station is located at the same level of fibre optic receiver to capture the most precise external reading to support research finding. The installation of mini meteorological station is shown in Figure 1. Outside temperature sensor and humidity sensor are shown in Figure 2.

Figure 1 Mini meteorological station

Figure 2 Outside temperature sensor and humidity sensor

3.2 Internal Data Collection

While the external data measurement was operating, the internal parameter data collection also was running concurrently and being stored. The internal parameter involves 1 (one) relative humidity sensor and 1 (one) internal temperature sensor in Figure 3.

Figure 3 Inside temperature sensor and humidity sensor

All sensors (totalling 4 numbers for internal and external) were connected to a desktop computer located at external wall outside the building. The computer needs to be outside to avoid internal heat generated by the desktop computer that may influence the internal heat built-up by the equipment [31].

3.3 Data Analysis

In order to produce a comprehensive analysis from the data collected, a comparison analysis approach will be considered in this research. The analysis is expected to disclose the potential of the fibre optic daylighting system in Malaysia skies and at the same time will reveal how the human comfort parameter being affected by the system. This research investigated the effects of fibre optic daylighting in building interior using simplified comparative method as implemented by [31, 32] through the profile of heat and relative humidity (RH):

Humidity is simply a measure of amount of water vapour in the air. The more water vapour, the more humid it is. Heat and relative humidity are the parameters that are important in determining human comfort in a space. The higher the temperature of the air, the less water vapour the air can hold. That makes sense because air molecules and water vapour molecules are moving faster at higher temperature [33].

[34] discovered that an optimum relative humidity based on the research made in Shah Alam, Selangor was 73%. The baseline value is important as a comparison of humidity value will be recorded in this research in relation to the analysis at later stage.

4.0 RESULTS AND FINDINGS

As discussing the monitoring results in this section, daily data collected from 17th May 2013 until 2nd June 2013 is cropped and analyzed between 8:00 AM to 6:00 PM daily since this is considered as normal daytime working hours for offices. Although the data was collected continuously during that duration, this actual cropped time was selected to constitute the typical usage time of an office room and the purpose of simplified on analysis approach.

The following analysis will consider three major weather conditions in tropical climate on representing overall climatic condition available in determining the potential of fibre optic daylighting system for interior illumination which are:

i) Hot Sunny Day with Intermediate Blue Sky (Date selected 22nd May 2013, 28th May 2013 and 1st June 2013)
ii) Moderate Sunny Day with Intermediate Mean Sky (Date selected 18th May 2013, 29th May 2013 and 30th May 2013)
iii) Overcast and Intermediate Overcast Sky (Date selected 20th May 2013, 23rd May 2013 and 24th May 2013).

The segregation of weather is very essential in presenting the results and to ease the overall understanding of this topic based on the objectives of the research. Other date than selected above will not be discussed. The explanation on the findings under this objective is conducted by comparing two days of the humidity result from the system during "ON" and "OFF" in Table 5.

Table 5 Average reading of external illuminance, solar radiation and relative humidity for overall data collection during system ON and system OFF

DATE	FIBRE OPTIC SYSTEM STATUS (ON / OFF)	AVERAGE READING				
		ILLUMINANCE EXTERNAL (LUX)	OBSERVATION OF SKY CATEGORY	SOLAR RAD. (W/m^2)	RELATIVE HUMIDITY	
					EXT. RH, %	INT. RH, %
18-May 2013	Fibre Optic Daylighting System **ON** FOR DATA COLLEC-TION	57,850	intermediate mean	510	66	63
19-May 2013		59,629	intermediate mean	528	70	65
20-May 2013		48,462	overcast	420	78	67
22-May 2013		72,251	Intermediate blue	654	57	59
23-May 2013		49,791	overcast	442	61	62
24-May 2013		44,413	overcast	386	67	63
25-May 2013		55,594	intermediate mean	487	65	64
26-May 2013		49,108	overcast	427	72	65
27-May 2013		66,059	Intermediate blue	592	61	64
28-May 2013		66,196	Intermediate blue	581	62	61
29-May 2013		56,965	intermediate mean	500	69	74
30-May 2013		58,247	intermediate mean	515	65	72
31-May 2013		92,025	Intermediate blue	608	61	71
1-June 2013		70,300	Intermediate blue	621	59	68
2-June 2013		11,785	overcast	99	99	75
3-June 2013	Fibre Optic Daylighting System **OFF** FOR DATA COLLEC-TION	57,214	intermediate mean	507	64	76
4-June 2013		53,029	intermediate mean	464	71	74
5-June 2013		62,888	intermediate blue	549	65	73
6-June 2013		65,315	intermediate blue	571	60	71
7-June 2013		77,615	Intermediate blue	690	60	68
8-June 2013		57,604	intermediate mean	508	67	68

On 22nd May 2013, the external average illuminance recorded is 72,251 lux where solar radiation averaged at 654 W/m^2 meanwhile on 7th June 2013, the average external illuminance recorded is 77,615 lux with solar radiation averaged at 690 W/m^2. Both dates are selected to compare the effect on relative humidity in **intermediate blue sky** from the operation of fibre optic daylighting system.

On the other hand, during **intermediate mean sky**, the data collected showed almost similar reading for both 18th May 2013 and 3rd June 2013 where the external illuminance averaged at about 57,500 lux for both days and the average solar radiation recorded is about 510 W/m^2.

Comparing the days, it is suggested that the overall form of graphs as shown in Figure 4 and Figure 5 for both selected days where overall patterns showing a close similarity during both system ON or OFF and no peculiar formation can be noticed.

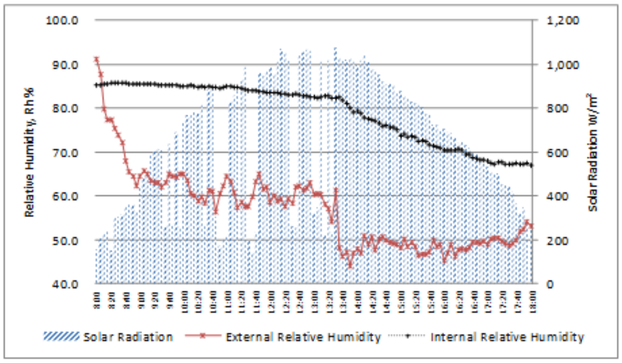


Figure 4 External solar radiation and humidity recorded for 22nd May 2013

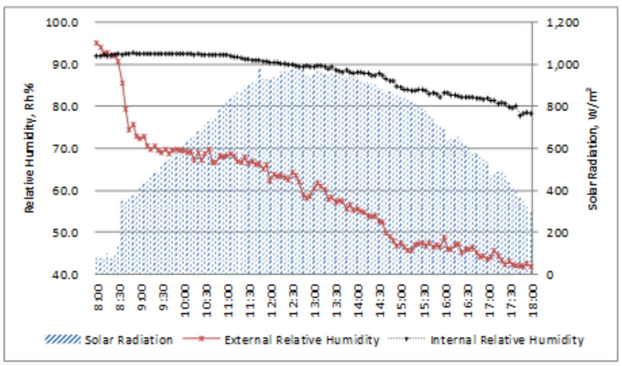


Figure 5 External solar radiation and humidity recorded for 7th June 2013

It is notable that the external relative humidity starts at almost the same figure ranging from 90% RH to 100% RH for all selected days. During intermediate blue sky (22nd May 2013 and 7th June 2013) which was considered as highly temperature with sunny days, the external humidity recorded a decrease with a different of 36% to 38% RH representing about 25% when comparing the humidity on early morning and late evening. However during intermediate mean sky (18th May 2013 and 3rd June 2013), the different is detected mostly due to weather condition on 2nd June 2013 where having all day rain, even though the external parameters showing a close similarity for both days. It is obvious that even the data collected showing great resemblance in external parameters for selected days, the actual parameter recorded is identical and unique for every single day that can be concluded here as uncontrolled and involving complex parameters that are always different daily.

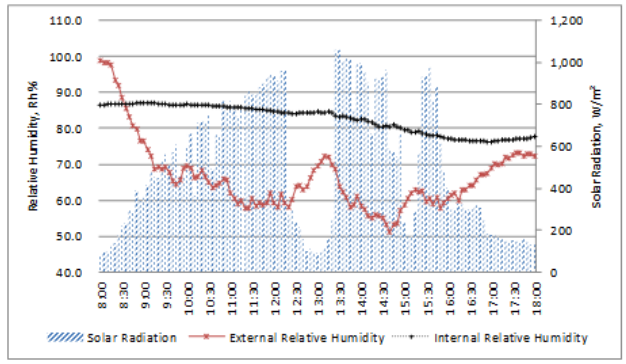


Figure 6 External solar radiation and humidity recorded for 18th May 2013

Figure 6 and Figure 7 shows the results obtained for intermediate mean sky (18th May 2013 and 3rd June 2013) in comparing the humidity effects due to the application of fibre optic daylighting system. The internal humidity recorded a decrease on 18th May 2013 and 3rd June 2013 which the different of humidity is about 5% in late evening compared to early morning. The experimental building is windowless and completely dark for internal light measurement that can be speculated here that during intermediate mean sky, due to moderate temperature outside and enclosed spaces using for humidity recording with no wind exchange and movement, the internal humidity can be sustained in longer period where the results shown that there is no major changes in humidity inside the building as shown in Figure 3 and Figure 4.

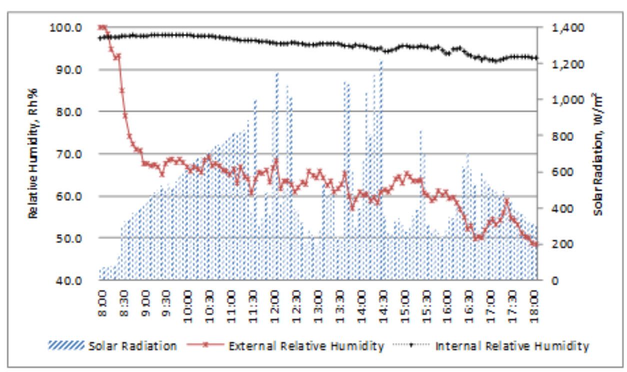


Figure 7 External solar radiation and humidity recorded for 3rd June 2013

5.0 CONCLUSION

It can be concluded here that the fibre optic daylighting system does not significantly influence the internal relative humidity parameter since the building is totally dark and enclosed and yet no notable change were detected for internal humidity during data analysis even the external relative humidity is fluctuate.

For internal relative humidity, the research found that no notable effect from the application of fibre optic daylighting system by comparing two set of date representing Hot Sunny Day with Intermediate Blue Sky and Moderate Sunny Day with Intermediate Mean Sky through experimenting the system ON and OFF during the whole data collection process. Both heat and humidity are the parameters that influenced the human comfort in a space.

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