ELSEVIER (https://www.elsevier.com)
ELSEVIER

SEARCH MENU

Energy Conversion and Management: X - Editorial Board

Editor-in-Chief

Mohammad Ahmad Al-Nimr

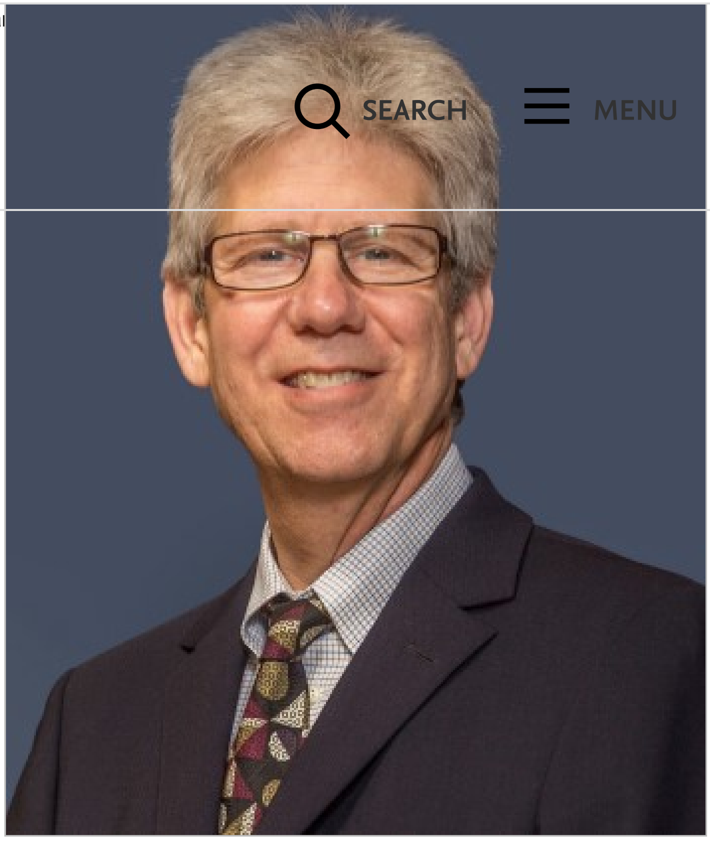
Qatar University, College of Engineering, Department of Mechanical & Industrial Engineering, Doha, Qatar
Email Mohammad Ahmad Al-Nimr (https://www.journals.elsevier.com:443/energy-conversion-and-management-x/editorial-board/mohammad-ahmad-al-nimr)

Editors

Marc Rosen

University of Ontario Institute of Technology, Oshawa, Ontario, Canada
Email Marc Rosen (https://www.journals.elsevier.com:443/energy-conversion-and-management-x/editorial-board/marc-rosen)

ELSEVIER



ELSEVIER (https://www.elsevier.com)

SEARCH

MENU

ELSEVIER

Energy Procedia

Open access

6th International Building Physics Conference, IBPC 2015

Edited by Marco Perino, Vincenzo Corrado
Volume 78,
Pages 1-3502 (November 2015)

page 3 of 6

ISSN: 1876-6102

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 1787 – 1792

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Long-term monitoring and simulations of the daylighting and thermal performance of an anidolic daylighting system on a tropical urban house

Floriberta Binarti[a]*, Prasasto Satwiko[a]

[a]*Architecture Department, Atma Jaya Yogyakarta University, Jl. Babarsari 44 Yogyakarta 55281, Indonesia*

Abstract

A poorly lit interior due to high external obstruction from the neighbourhood is a common problem in dense urban settlements. To improve the daylighting performance; meanwhile, to maintain its thermal performance of a living room in a tropical urban house, an anidolic daylighting system (ADS) was applied on the east facade. Long-term monitoring and simulations were conducted before and after the ADS installation to assess the room's daylighting and thermal performance. The living room's daylight levels and the daylighting glare probability (DGP) were analyzed using Radiance and Evalglare based lighting simulation softwares. Design Builder was employed to observe the thermal impact of the application. Whereas, the long-term monitoring of the ADS performance covered field measurements of the living room's daylight levels, DGP, air temperature, relative humidity and ADS collector's surface temperature before and after the ADS installation. Long-term monitoring and simulation results prove that ADS is a promising solution for daylighting problems in tropical regions. It convincingly improved the daylight levels within the imperceptible glare range without the increasing of the indoor air temperature.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: anidolic daylighting system (ADS); daylighting performance; monitoring; simulation; thermal performance; tropics;

1. Introduction

Anidolic daylighting system (ADS) is an edge-ray principle based daylight redirecting system. It was initially intended to improve the daylighting performance of wide rooms in temperate climates under overcast sky conditions [1]. Several studies on ADS in hot tropics have shown the outstanding daylighting performance and their potency to

* Corresponding author. Tel.: +62-274-487711; fax: +62-274-487748.
E-mail address: flo.binarti@gmail.com

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.307

save the lighting energy [2-3]. Thanks to the edge-ray principle and its high collector reflectance, an ADS in hot tropics also potentially saves the building energy for cooling [4]. These advantages make ADS as an ideal daylighting system in hot tropics possible. To describe this prospect in detailed, this study presents long-term monitoring and simulations of a successful ADS application on a tropical urban house. Since the study on ADS thermal performance is still rare, focusing on the thermal impacts of the ADS application in the tropics would be valuable.

2. Methods

2.1. Description of the ADS and the urban house

An ADS was applied on a tropical urban house in Yogyakarta, Indonesia (7º49'S and 110º21'E) as a solution of a badly lit living room due to high external obstruction from the neighborhood. The living room is enclosed by a corridor on the east side, a terrace with high external obstruction from the neighbor building on the north, a bedroom on the west side and a kitchen on the south. Small dwelling on the east reduces the opportunity to achieve high vertical sky component (VSC) of side window on the east facade of the house. This living room is used for television activities.

Based on the attainable sky factor (SF) and the distance of light travel from the ADS collector to the living room, the east facade was considered as the best location for mounting the ADS. The ADS comprises a 40 cm-wide collector, a light transport medium and an opposite parabolic ceiling installed on the deepest perimeter of the living room that functions as a light diffuser. A simple edge-ray principle [1,5] was used to design the parabolic collector. The collector is made of stainless steel and covered by 6 mm-thick clear glass tilted on 15º and mounted on a 300 cm-long and 40 cm-high unglazing clerestory situated on the external wall of the corridor. This clerestory size corresponds to 9% of the window to floor area of the living room. Two clerestories with the same dimension and height from floor level on both wall sides of the corridor are connected by an ADS tunnel serving as a light transport medium. This tunnel is enclosed by pure white painted gypsum board. The 2.58 m-high (from the living room's floor level) internal clerestory and the 1.50 m-deep ADS tunnel are expected to prevent glare in the living room.

2.2. Simulation methods

Simulations were undertaken to analyze the living room's daylighting and thermal performance (2 weeks) before and (10 months) after the ADS installation. Radiance [6,7] and Evalglare [8] based softwares were used to perform the daylight factor (DF), the indoor illuminance (E_i) and the daylight glare probability (DGP). DGP is a glare rating derived from subjective user evaluations inside lit rooms and considering the most factors that contribute to visual discomfort. The living room's thermal performance was simulated by Design Builder [9] that utilizes Computational Fluid Dynamics (CFD) and EnergyPlus (E+) [10] simulation engines.

Radiance adopts the BRE split flux method to calculate the DF and the backwards ray-tracing algorithm [6] to predict the E_i of each particular point in a certain zone. In this study, DF was calculated under overcast sky condition. All daylighting simulations were set-up with high calculation accuracy and 4 indirect reflections. Instant maps were simulated to visualise the illuminance on the measurement dates, which have regular patterns of E_{amb} (based on the measurements) and are close to the June solstice, September equinox, October15 (the highest altitude) or December solstice.

To figure out the thermal impact phenomenon of the ADS in the tropics, 2 simple models were developed using Design Builder. The models have identical geometry, photometric and thermal properties, except the ADS presence, and set-up under the same climatic conditions. Their zone (living room) temperature distributions were simulated by CFD using K-e turbulence model. The internal boundary conditions were defined by E+ calculation results of the average zone air temperature, the external temperature, the internal surface temperatures, and the air flows on October 15 at 08:00 and 11:00.

2.3. Monitoring

Long-term monitoring involved field-measurements of the E_{amb}, the indoor and outdoor illuminance, air temperature, relative humidity, the collector surface temperature and the living room's DGP. Monitoring of the indoor climate (illuminance level, air temperature and relative humidity) was conducted for 2 different location points on the north-south axis of the room, which represent the entire work plane of the 3.3 m-wide living room. The indoor illuminance (E_i), air temperature (T_i) and relative humidity (RH_i) were monitored using 2 analog 4 in 1 environment testers LM-8000 (its accuracy is 5% for light intensity, 1% for air temperature and 1.2 to 4% for relative humidity) placed at seat height in the middle of the living room. The outdoor illuminance (E_o), air temperature (T_o) and relative humidity (RH_o) measurements were carried out using luxmeter LX-107 (the accuracy is 5%) and 4 in 1 environment tester LM-8000. These instruments were located around the house under relatively constant shading of a tree examined by Sun Path facility in Ecotect software [7]. Digital equipments, i.e. Hobo datalogger U12-012 for the indoor measurement and Hobo datalogger UA 002-08 for the outdoor measurement, were set-up with 5' time interval and measured on the same position to maintain the measurement validity. By using a Paired T test, the ADS thermal impact can be assessed from the p value or Sig. (2-tailed). More than 0.05 of the p value means that the ADS can not modify the indoor thermal conditions.

To observe the heat transfer effect of the ADS installation, surface temperature of the collector and living room's wall was measured hourly on several days using infrared thermography FLIR i5 (the thermal sensitivity is < 0.1ºC with accuracy is ±2 ºC or ±2% of reading and IR resolution is 100 x 100 pixels). The measurement results would describe the real surface temperature of the living room's internal surface and the ADS collector.

The real DGP were obtained by analyzing High Dynamic Range (HDR) photos of the living room using Evalglare software. The HDR photos were produced by merging 7 fisheye photos with exposure variation using Photosphere software [11]. These photos were taken by Nikon D7000 digital camera with Nikor 10.5 mm GED fisheye lens at time when the sun was located within zenithal area.

3. Results and discussions

3.1. Daylighting performances

Simulated DF of the living room with ADS (1.03% at point A and 1.05% at point B) raised slightly more than the recommended value for a living room (1.0%). As a comparison, the simulated DF of the living room without ADS only reached 0.75%. These results came to a decision of the ADS installation.

Seventy three percent of the monitoring measurements were taken under clear sky with sun and the remaining measurements were conducted under overcast and partly cloudy skies (see Fig 1 (right)). To represent the real sky conditions depicted in Fig. 1(right), therefore, E_i was calculated on several dates under clear sky with sun (from 08:00 to 14:00) and overcast sky (at 15:00 and 16:00). Only simulations on June 21 were run under clear sky with sun (from 08:00 to 11:00) and overcast sky (at 12:00 to 16:00) to resemble the sky conditions on that day.

Average simulated E_i of the living room with ADS could reach > 50 lux. The minimum standard E_i for a living room dominated by watching television is 50 lux, whereas 100 lux is the IESNA standard E_i for regular living room. The hourly E_i simulations (see Fig. 2) resulted in moderate fluctuations of both hourly E_i profiles of the living room before and after the ADS installation. The time of peak simulated E_i of the living room with ADS shifts depending on the time when the SF was maximum.

Figure 2 and 3 describe the more fluctuating field-measured E_i of the living room with ADS compared to the simulated E_i with ADS. On the contrary, field-measured E_i of the living room without ADS are less wavering. Two reasons might cause these hourly E_i profiles are: (a) as the real sky luminance is subtle, real E_{amb} seems more extreme than simulated $E_{amb;}$ and (b) the simulation tends to overestimate the interreflected light flux.

High increasing of the E_i occurring before 11:00 created high hourly E_i profile over the seasons (except on several days under cloudy skies). Similar profile was presented by the long-term monitoring results of the illuminance ratio (E_i/E_o). Only at 8:00 the E_i/E_o of the east-facing ADS are higher than the E_i/E_o at 9:00. Direct morning sunlight entering the ADS collector at 8:00 produced high E_i.

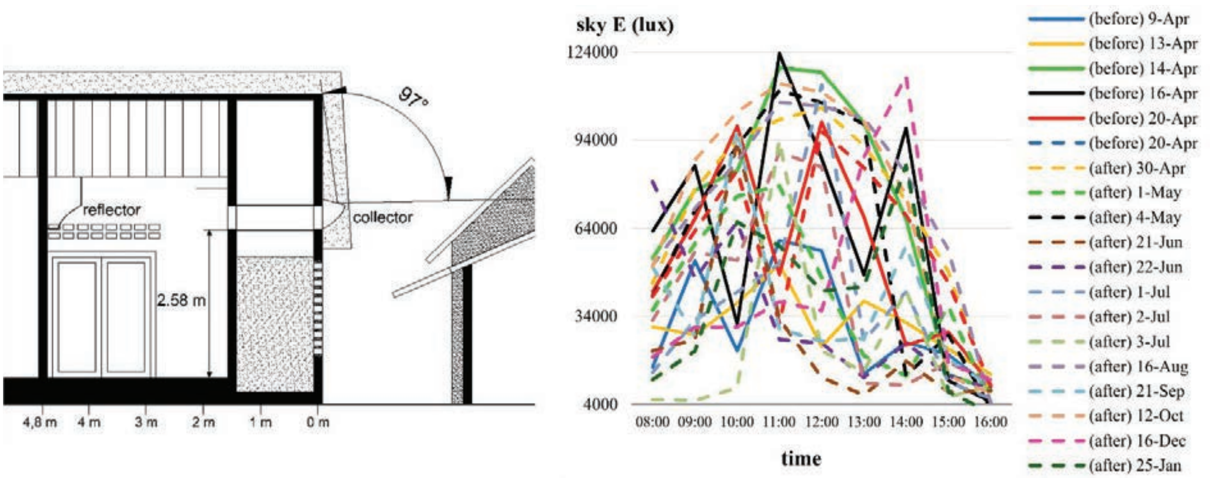


Fig. 1. A section of the urban tropical house with ADS (left) and Ambient horizontal illuminances during 10 month monitoring (right).

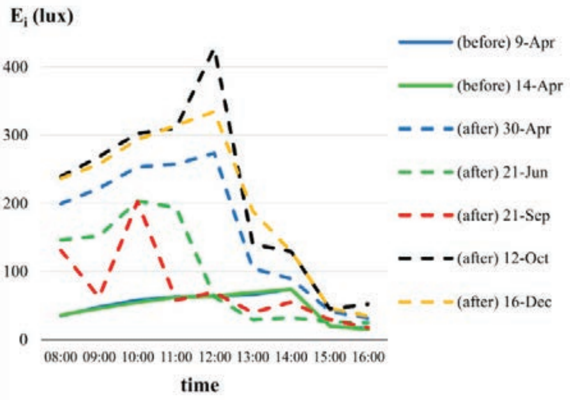


Fig. 2. Simulated E_i of point A in the living room on several selected dates.

Diffuse morning sunlight from low altitude, directly falling on the parabolic reflector, produced high illuminance at 08:00. A combination of the high E_i and the low E_{amb} at 08:00 even created the highest E_i/E_o. These conditions occurred intensely from April to June. On June 21 and July 1, the hourly profiles of E_i/E_o appear more flat because some parts of the house covered the measurement location of the E_o in the afternoon.

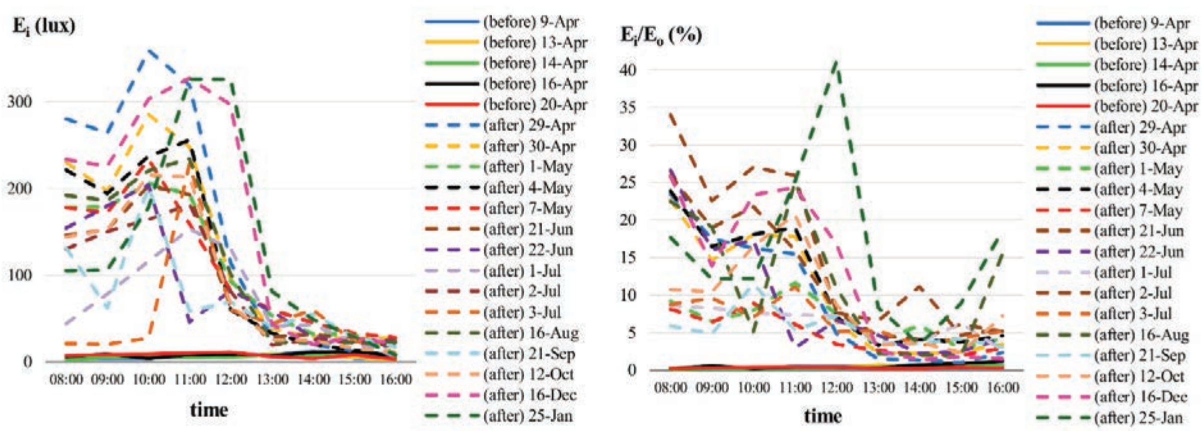


Fig.3. Field-measured E_i (left) and field-measured E_i/E_o (right) at point A in the living room.

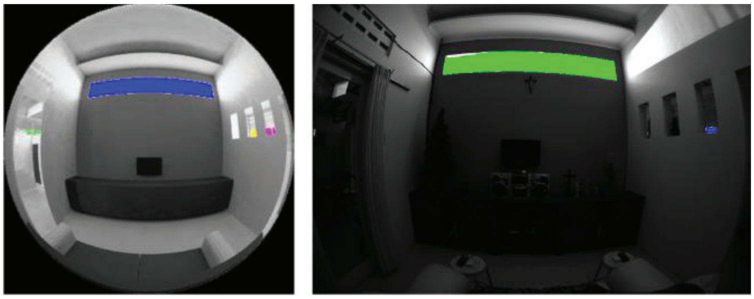


Fig. 4. Simulated DGP on August 16 at 11:00 (left); measured DGP on August 16 at 11:00 (right).

The simulated DGP of the existing living room on several dates after the ADS installation under clear sky are 19% on March 21 at 11:00 and 19.7% on October 15 at 11:00. Whereas, simulated DGP of the living room with ADS depicted low DGP of the living room. Although the DGP of the room with ADS increased to 25.6% on March 21 at 11:00 and 26.0% on October 15 at 11:00, the values are still in the imperceptible glare range. Due to the higher E_{amb} (see Fig 1b), the DGP measured on August 16 (16.0%) resulted in higher DGP than the DGP measured on October 12 (2.1%). From the simulation and monitoring results it can be concluded that the ADS installation increases the DGP of the living room at sitting occupant's eye level, but still keeps it in the imperceptible glare range. The ADS collector on 2.58 m-high from the floor level and 1.5 m-deep light tunnel between the collector and the living room could avoid the occupant view from the incoming direct sunlight through the collector.

3.2. Thermal performances

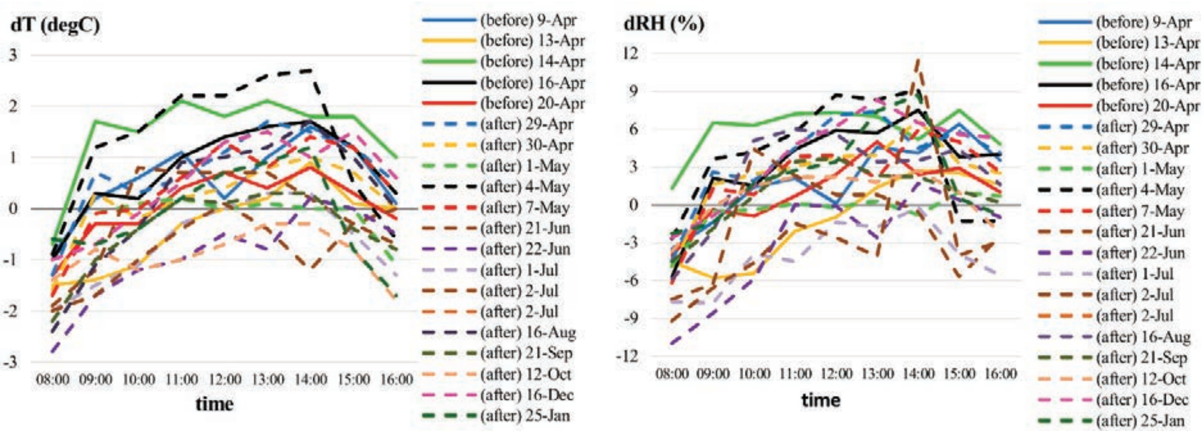


Fig. 5. Field-measured air temperature differences (left); Field-measured relative humidity differences (right).

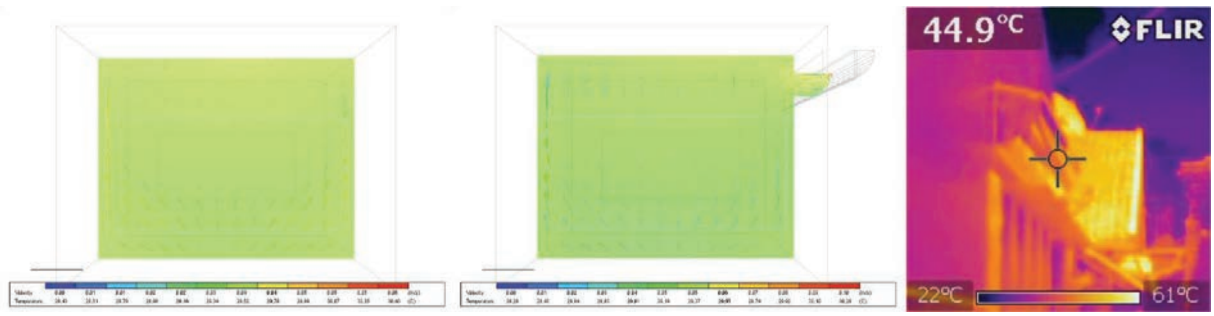


Fig. 6. CFD simulated air temperature and velocity distributions on October 15 at 08:00 of simple model without ADS (left) and with ADS (middle); ADS surface temperature measured using FLIR i5 on December 16 at 11:03 (right).

Figure 5 shows that field-measured air temperature (T_o-T_i) and relative humidity differences (RH_i-RH_o) after installation (dashed line) are still in the same range as the T_o-T_i and RH_i-RH_o before installation (straight line). The paired T test of the T_o-T_i explained that T_o-T_i before and after the ADS installation has a strong (the correlation is close to 1) and significant correlation. The p value (> 0.05) and the mean T_o-T_i (0.59 deg C) indicated that the ADS installation did not modify the indoor air temperature.

Insignificant correlation between the RH_i-RH_o measured before and after the ADS installation demonstrated by its low correlation (0.59). However, there is only small RH_i-RH_o due to the ADS installation described by the p value (< 0.05) and the mean (0.82%). This insignificant correlation might be caused by the combination of the very low outdoor air humidity with the high indoor air humidity on May 4 and July 1. An exceptionally small activity carried out inside the house during these days might have increased the moisture content.

E+ calculation resulted in the same zone air temperature on October 15 of the model without ADS and with ADS, i.e. 30 ^oC at 08:00 and 32 ^oC at 11:00. Therefore, there is no significant differences in the zone internal surface temperature input as the boundary conditions between model with and without ADS. These conditions created similar CFD simulated air temperature distribution of both models. Only slightly modified airflow revealed above the occupancy zone due to the ADS installation (see Fig. 6 (right) and (middle)). These results explain that low intensity of solar radiation directly entering the building through the ADS at 08:00 could not increase the room's air temperature. Stainless steel (the ADS material) seems to work efficiently as light reflector. Its relative low thermal conductivity compared to other metals could avoid the ADS to be a heat sink under high solar radiation. Fig. 6 (right) shows lower surface temperature of the stainless steel compared to the neighbor's burnt-clay roof surface temperature.

4. Conclusions

Despite a discrepancy between long-term monitoring and simulation results, both denote that the east-facing ADS convincingly improve the daylighting performance of the living room without significant thermal impact. Sufficient daylight levels entering the room through 2.58 m-high clerestory with 1.5 m-deep light tunnel could maintain the room's DGP in the imperceptible glare range. Since clear sky with sun frequently occurred during the monitoring, the ADS performs a strong hourly illuminance profile. High reflectance of the collector material reflects most of the flux as light energy, whereas the direct sunlight entering through the ADS collector is not sufficient to increase the living room's air temperature.

Acknowledgements

The financial support from the Directorate of Higher Education Republic Indonesia, Ministry of Research, Technology and Higher Education in the scheme of *Hibah Bersaing* under the contract numbers: 006/SP-HB/II/2014 and 005/HB-LIT/III/2015 (Government to University) is gratefully acknowledged. Authors also thank to Dr. Amos Setiadi for supporting the facilities.

References

[1] Scartezzini JL and Courret G. Anidolic daylighting systems. *J Sol Energy* 2002; 73(2): 123–135.
[2] Wittkopf SK. Daylight performance of anidolic ceiling under different sky conditions. *J Sol Energy* 2006; 81: 151–161.
[3] Praditwattanakit R, Chaiwiwatworakul P and Chirarattananon S. Anidolic Concentrator to Enhance the Daylight Use in Tropical Buildings. ftp://202.28.64.61/04.April2013/Dowload/print/139_Rut%20Praditwattanakit.docx. (accessed on August 7, 2014).
[4] Binarti F And Satwiko P. An east-facing anidolic daylighting system on a tropical urban house. *J Indoor and Built Env.* Prepublished March 6, 2015. DOI: 10.1177/1420326X15574748.
[5] Linhart F, Wittkopf SK and Scartezzini JL. Performance of anidolic daylighting systems in tropical climates – parametric studies for identification of main influencing factors. *J Sol Energy* 2010; 84: 1085-1094.
[6] Ward G. Desktop Radiance Software. Lawrence Berkeley Laboratory, Berkeley, 2002.
[7] Marsch A. Ecotect Software v.5.5. Square One, Cardiff, 2005.
[8] Wienold J. Evalglare Software. Fraunhofer Institute for Solar Energy System, Freiburg, 2005.
[9] Tindale A and Potter S. Design Builder v.4.0. Gloucestrshire, 2014.
[10] Crawley DB, Lawrie LK, Winkelmann FC, Buhl WF, Pedersen CO, Strand RK, Liesen RJ, Fisher DE, Witte MJ, Henninger RH, Glazer J and Shirey D. EnergyPlus v.8.1. Atlanta, Georgia, 2013.
[11] Ward G. Photosphere for Mac. Anyhere software, Los Angeles, 2003.