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Performance studies of anidolic concentrator with light pipes for day lighting in buildings

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***Abstract*—Performance of conventional vertical light pipes with acrylic domes is highly dependent on the sky condition where efficiency is low for overcast sky condition. Anidolic concentrators are suited for day lighting applications in overcast sky due to non imaging optics. This paper intends to assess the performance of an anidolic concentrator designed with an acceptance angle of 60° in the geographical location of Chennai. The light output of the concentrator is assessed in varying solar altitude angles in a day. Performance assessment of the concentrator with a model light pipe was done with overcast and clear sky conditions and with high and low solar altitude angles in different times of the day and in a year. It was inferred that by designing an anidolic concentrator with an acceptance angle suited for a range of solar altitude angle in a day of a location, day lighting to the interiors in clear and overcast sky is possible. The design of the anidolic concentrator can differ for high latitude and low latitude regions by varying its acceptance angle.**

Keywords*—Anidolic concentrator; day lighting; overcast sky; light pipes

I. INTRODUCTION

High rise commercial buildings built in dense urban areas provide sky obstructions for rooms on lower floors and in spaces deep inside. Innovative day lighting technology like a light pipe which is a light transport system can provide day lighting deep inside the rooms. A light pipe has three components – an outside collector, usually a transparent dome to remove UV rays and prevent dust, a pipe with highly reflective lining and a diffuser/luminaire to diffuse light inside a building. The performance of the pipe is highly dependent on sky conditions where the performance decreases significantly with diffuse or overcast sky conditions [1]. For such conditions non imaging optics can be utilized which avoids the need to keep the collector aperture pointed at the sun. Anidolic or non imaging systems are used specifically to redirect diffuse light from the sky to the interiors. They are suited in areas where overcast sky conditions prevail for a longer duration [2]. Anidolic ceiling, integrated anidolic ceiling, anidolic solar blinds [3] and anidolic zenithal light guide [4] have been used for day lighting in such conditions. This paper deals with the performance study of anidolic concentrators as collectors for light pipes. The variation in light output is determined with change in solar altitude and azimuth angle as well as in varying sky conditions.

II. CONCEPT OF ANIDOLIC CONCENTRATION

An anidolic concentrator or compound parabolic concentrator (CPC) is built with highly reflective material and the concentration is achieved by its parabolic form [5].These concentrators act as radiation funnel and do not have a focus [6]. It is one of the concentrators which has the highest possible concentration permissible by thermodynamic limit for a given acceptance angle [7].

The construction of the anidolic concentrator is shown in figure 1. It has two parabolae sections AB and CD of parabola 1 and 2 respectively. AD is the entry aperture area while BC is the exit aperture area. The axis of both parabolae is oriented such that C is the focus of parabola 1 and B is the focus of parabola 2. The height of the concentrator is such that tangents at A and D are parallel to the axis.

The acceptance angle of the CPC is the angle AED which is obtained by joining the focus to the opposite aperture edge. Diffuse light falling on the entry aperture of the device is collected and concentrated onto a smaller exit aperture [8].

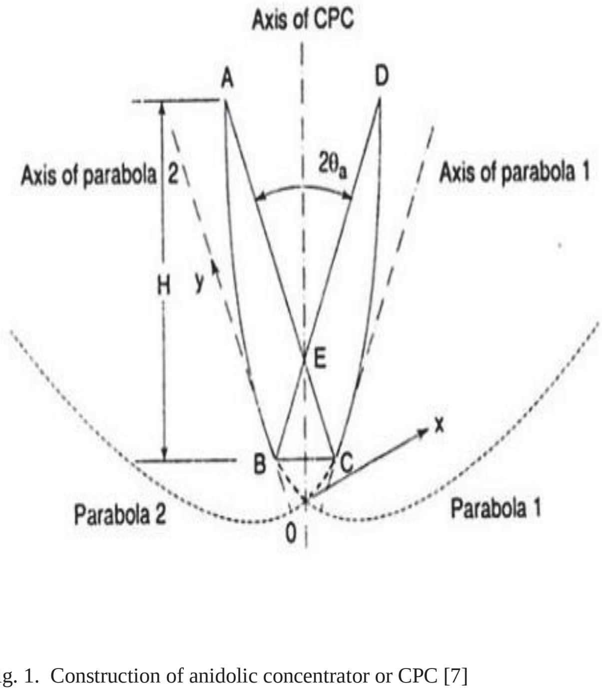

Fig. 1. Construction of anidolic concentrator or CPC [7]

The anidolic concentrator have an acceptance angle within which it concentrates light while incident rays beyond this angle is rejected back (fig 2). The entry aperture has a lower angular range while the concentrated light is emitted out in a wider angular range.

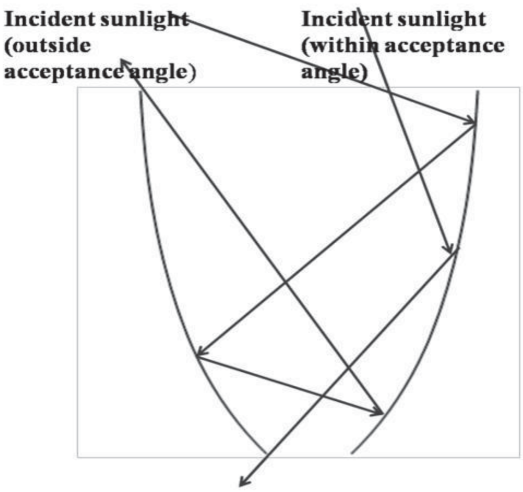

Fig. 2. Anidolic concentrator concentrates light within acceptance angle [5]

Light predominantly comes from the zenith in overcast sky and from the horizon in clear sky. Since conventional acrylic domes perform poorly in diffuse sky condition and overcast sky condition anidolic concentrators which face predominantly the zenith can be integrated with the light pipes as they perform well in overcast skies.

III. MATERIALS AND METHODOLOGY

An anidolic concentrator was fabricated of 12 mm thick stainless steel sheet with an acceptance angle of 60°. With 300 mm square aperture at the top and 150 mm square aperture at the bottom, the height of the concentrator was truncated to 320 mm to make it compact. Truncation of a CPC at the top portion can be done without significant loss in light concentration [7]. Figure 3 represents the plan and elevation of the concentrator designed.

A Computer numerical control (CNC) machine was used for cutting the profile of the concentrator. The cut profiles were bent according to the profile and welded together. To prevent the entry of rain and dust into the anidolic concentrator, a transparent acrylic top can be used to cover the inlet aperture.

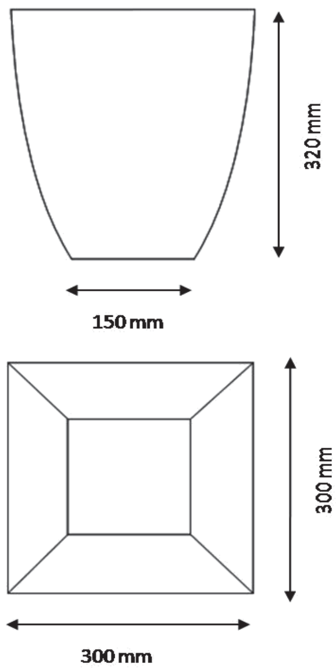

Fig. 3. Plan and elevation of Anidolic concentrator

The variation in light output for the anidolic concentrator was done with variation of solar altitude angle in a day. Light output was measured using Extech (HD 450) data logging lux meter. The geographical location chosen for study was Chennai (13°4'N, 80°15'E, GMT +5.5 Hours). The variation of solar altitude angle from 8.00 hours to 17.00 hours for Chennai in a year is presented in figure 4. It is seen that during the period of May to August the sun is at hgh solar altitude angle and during September to April at lower altitude angles.

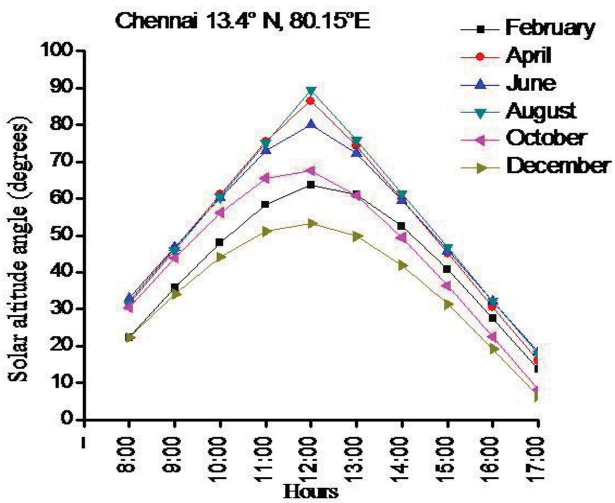

Fig. 4. Variation of solar altitude angle in an year in Chennai

Further, the anidolic concentrator and an acrylic dome with a light pipe were taken for further studies with the following conditions –

a) Clear sky at high solar altitude angle
b) Overcast sky at high solar altitude angle
c) Clear sky at low solar altitude angle
d) Overcast sky at low solar altitude angle

A. Effect of solar altitude angle on light output

The effect of solar altitude on the light output of the anidolic concentrator was assessed at various time of the day (9:00 to 16:00 hrs) in the month of April in clear sky condition. The solar altitude angle varied from 47° at 9.00 hours and reached a peak at 87° at 12.00 hours.

The light output was measured at the base of the concentrator at the exit aperture. As the solar altitude angle increased, the performance of the concentrator also increased. It was observed that below 60° solar altitude angle, the incident light reflected back without exiting through the output aperture (fig 5).

It was observed that concentrator performed well between 10:00 and 14:00 hrs (fig 6). At 12.00 hours the incident solar rays exited through the exit aperture without any concentration.

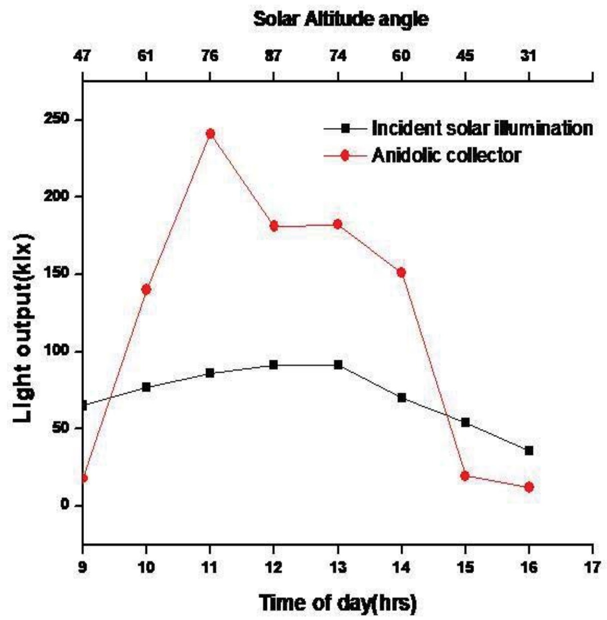

Fig. 6. Performance of anidolic concentrator at various time of the day

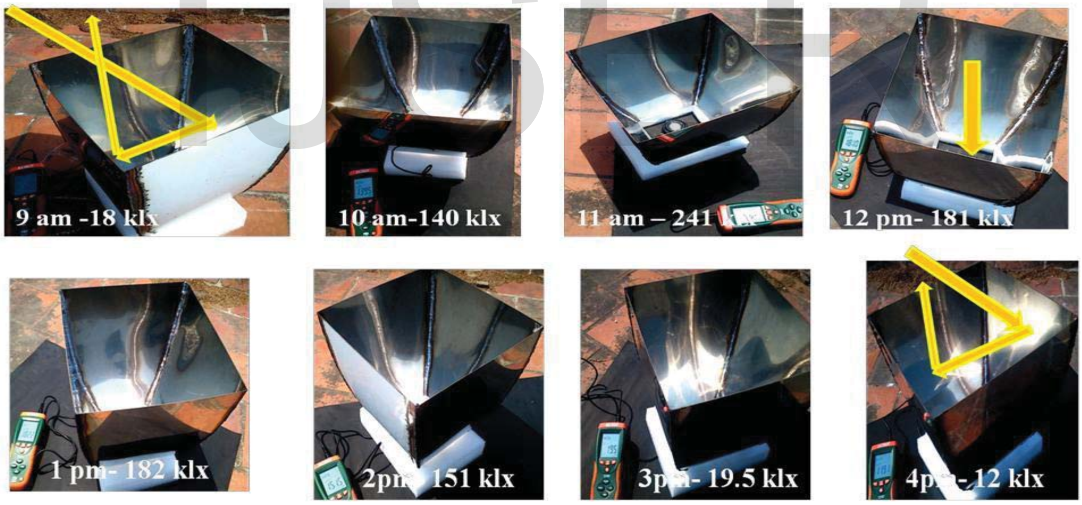

Fig. 5. Incidence of light into the concentrator at various time of the day

B. Performance of anidolic concentrator in varying sky conditions

Performance in light output for the conventional acrylic dome and the anidolic concentrator was done at different times of the year with varying sky conditions as well as in periods of high and low solar altitude angles with a model light pipe. Experiments were done with a model light pipe of aspect ratio 2, and the pipe was mounted on a box of size 400 mm x 400 mm x 100 mm. The illuminance was measured at the centre of the base of the box.

a) Clear sky condition with higher average solar altitude angle

Experiments were done in clear sky at different times of a day when the sun was in the northern hemisphere in May (fig 7). The solar altitude angle reached 62° at 10.00 hrs and attained a peak of 88° at 12.00 hrs. It again decreased to 60° at 14.00 hrs. The incident illumination varied with time of day from minimum of 77 Klux to 104 Klux at noon. The anidolic concentrator performed well within its acceptance angle (between 10.00 and 12.00 hours).The performance of the anidolic concentrator was low at 12:00 hrs since light directly fell into the exit aperture without concentration.

b) Overcast sky condition with higher average solar altitude angle

The performance of the concentrator was assessed on an overcast sky condition on different days in the month of May. The solar illuminance ranged between 12 and 32 Klux. The concentrator performed best with an illuminance ratio ranging from 0.3 to 0.48 within 10.00 to 14.00 hours (fig 7). The performance of the acrylic dome was poor compared to the anidolic concentrator.

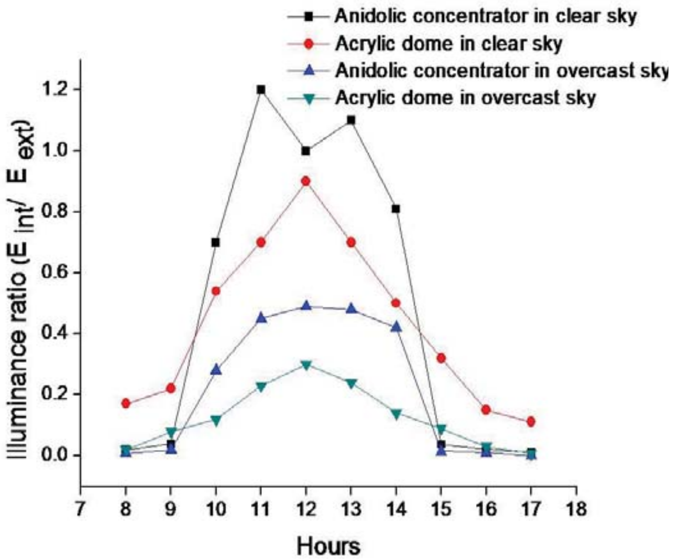

Fig. 7. Performance of anidolic concentrator and acrylic dome at high range of solar altitude angle with clear and overcast sky conditions

c) Clear sky condition with lower average solar altitude angle

The comparative performance of the model light pipe with anidolic concentrator and acrylic dome (fig 8) was assessed in the month of December when the solar altitude angle was low even during mid day. The solar altitude angle was 22° at 8.00 hours, reached a maximum at 53° and lowered to 7° at 17.00 hours. It was observed that due to the limitation of acceptance angle the anidolic collector performed poorly during this period.

d) Overcast sky condition with lower average solar altitude angle

Performance of the concentrator was assessed in overcast sky condition (fig 8) with predominantly cloudy condition in the month of December with the solar illuminance ranging from 7 Klux to 38 Klux. Due to the low solar altitude angle and due to the limitation of acceptance angle the efficiency was comparatively poor.

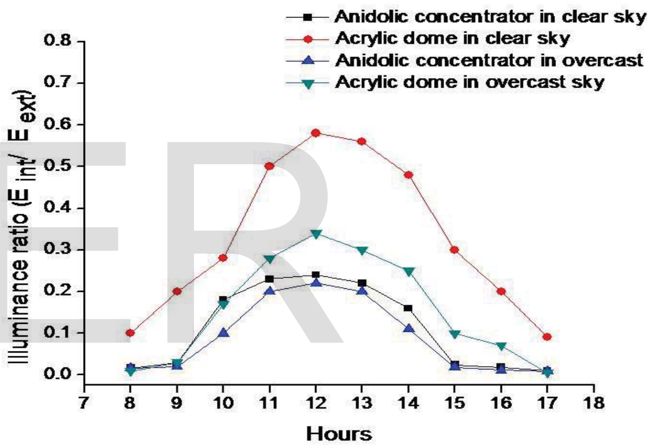

Fig. 8. Performance of the anidolic concentrator and acrylic dome at low range of solar altitude angle with clear and overcast sky conditions

IV. CONCLUSION

An anidolic concentrator was fabricated with an acceptance angle of 60°.

- Light concentration decreases when sun is at the zenith due to lack of reflection at the inner surfaces.
- The designed anidolic concentrator provided light concentration from 10.00 hrs to 14.00 hrs (at solar altitude angle beyond 60°) during summer for Chennai. During other times when solar altitude angle decreased below 60° the anidolic concentrator was found not effective.

- The anidolic concentrator provided good efficiency in clear sky and overcast sky when light was incident within its acceptance angle.
- Anidolic concentrators can be designed with acceptance angles specific to the location it is being used for the range of solar altitude angle in a time period.

Acknowledgment

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