A methodology to estimate solar radiation for design of thermally efficient buildings

Sustainable development of Indian cities is an essential pre-requisite for India to establish itself as a major economic power. Smart cities dwell on energy-efficient urban centres. The National Action Plan on Climate Change and the recently formulated plan for Smart Cities emphasize the need for energy efficiency. However, inadequate domestic finance and lack of public support impose sizeable constraints.

With over 2 million residential units built per annum[1], the residential sector of the Indian building industry is a major energy consumer. Furthermore, India is estimated to house 14% of the world's urban population from 2005 to 2025 (ref. 2), thus adding to energy woes. Due to over-expansion and over-crowding of metropolitan cities, the smaller towns are expected to house much of the Indian urban population in the near future.

Around 3000–5000 kWh of absolute electricity use in air-conditioned housing unit in warm humid/composite climate can be saved through energy-efficient measures, primarily aimed at reducing building's cooling needs[3]. Therefore, planning for thermal efficiency in building design and careful consideration of the local climate have become critical for sustainable development of Indian cities.

Detailed climatic data are available for some selected Indian cities. Though regional-level climatic data are easily available, variations in geographic location and physical features contribute to substantial variation in the local climate and consequently, the peak seasonal values. Information about the quantum of incoming solar radiation is lacking and is urgently needed for thermal design of built structures.

This study proposes a methodology, developed from a literature study, for estimation of incoming extraterrestrial radiation at any given place and time. It is expected to assist engineers and architects to determine the parameters essential for the design and development of thermally efficient buildings.

Due to the seasonal variation and atmospheric dynamics, the amount of solar radiation reaching the Earth's surface is highly variable. Besides the daily variation in its quantum, it gets further attenuated through scattering, absorption and reflection within the atmospheric path of transmission due to the presence of permanent gases (oxygen, ozone, carbon dioxide, etc.), water vapour, dust particles and cloud cover[4,5].

Duffie and Beckman[6] proposed a standard method for estimation of incoming extraterrestrial solar radiation at a given geographical location using the hour angle and geographical coordinates as necessary inputs. They correlated the extraterrestrial solar radiation with the nth day of the year to get the modified solar constant for that day. The modified solar constant is correlated with declination and solar zenith angle to estimate the incoming direct beam solar radiation for the given time instant (Figure 1 and Box 1). This can be integrated within hour angles set as limits to calculate the hourly beam solar radiation for a given location.

According to the Food and Agriculture Organization, Rome, the sky is defined as 'clear' when at least 75% of the incoming extraterrestrial solar radiation reaches the Earth's surface[7]. Therefore, estimation of 75% of the incoming extraterrestrial radiation gives the minimum value of the insolation to be considered for design of the built environment.

Sustainable development of Indian towns is fast becoming an undeniable necessity. Planning for thermal efficiency has therefore gained paramount

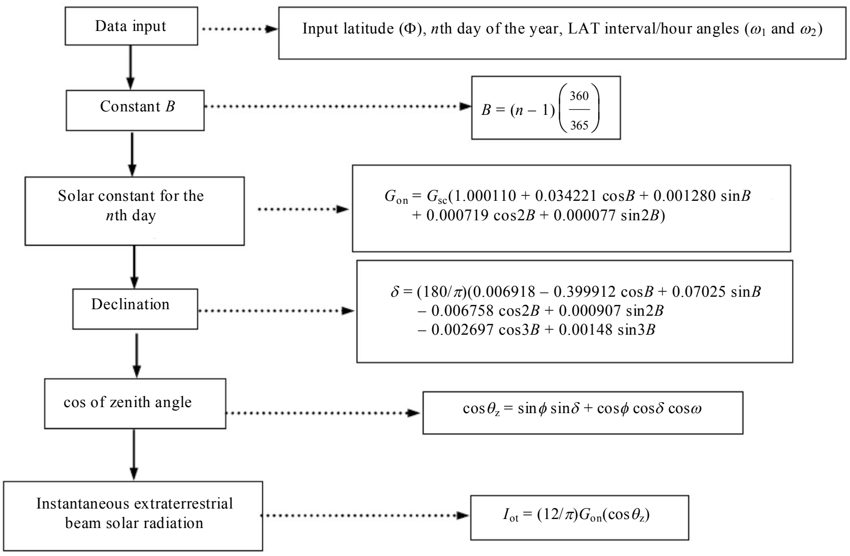

Figure 1. Methodology for the estimation of instantaneous extraterrestrial beam solar radiation.

Box 1. List of symbols used in Figure 1.

- G_{on} Extraterrestrial radiation incident on the plane normal to the radiation on the nth day of the year
- G_{sc} Solar constant – It is the energy from the sun per unit time received on a unit area of a surface perpendicular to the direction of propagation of the radiation at mean earth–sun distance outside the atmosphere
- I_{ot} Instantaneous extraterrestrial beam solar radiation
- n nth day of the year
- Φ Latitude
- δ Declination
- ω Hour angle
- θ_z Zenith angle
- ω_s Sunset hour angle

importance. However, unavailability of climatic data undermines the scope of thermally efficient planning. The proposed methodology uses the geographical coordinates and hour angle as necessary inputs to estimate the incoming extraterrestrial radiation. It therefore serves to establish the design parameters necessary for the thermal design of buildings in the absence of climatic data.

1. Reddy, B. V. V. and Jagdish, K. S., *Energy Build.*, 2003, **35**, 129–137.
2. http://www.mckinsey.com/insights/urbanization/urban_awakening_in_india
3. http://www.ee-homes.com/en/theprogramme/needforprogramme/dok/31.php
4. Bhattacharya, A. B., Kar, S. K. and Bhattacharya, R., *Ann. Geophys.*, 1996, **14**, 1051–1059.
5. Hoyt, D. V., *Solar Energy*, 1978, **21**, 27–35.
6. Duffie, J. A. and Beckman, W. A., *Solar Engineering of Thermal Processes*, John Wiley, New Jersey, 2006, 3rd edn.
7. Allen, R. G. *et al.*, FAO Irrigation and Drainage Paper 56; http://www.fao.org/docrep/x0490e/x0490e00.htm

Received 18 March 2016; revised accepted 1 August 2016

AABSHAR U. K. IMAM*
UTTAM K. BANERJEE

Department of Architecture and Regional Planning,
Indian Institute of Technology,
Kharagpur 721 302, India
**For correspondence.*
e-mail: aabsharimam@arp.iitkgp.ernet.in

A possible impact crater from Outer Continental Shelf off Cochin, Arabian Sea, India

During the Cruise SR-004, taken up in August 2014 by *RV Samudra Ratnakar* of the Geological Survey of India, high resolution sea bed survey by swath bathymetry and sub-bottom profiling were carried out in the outer continental shelf off the Cochin coast, 65 km SW of Cochin, an isolated large circular depression was observed in an otherwise gently sloping (0.8°) sea floor (Figure 1). Depth of the outer shelf in the eastern part of the depression is 155 m and 160 m on the western side. Part of a submarine channel has also been identified in the outer shelf and slope and indications of a few faults are seen in the vicinity of the shelf margin. These faults are about 60 to 70 km west of the coast occurring at depths varying from 100 to 350 m. One E–W trending fault is 2–2.5 km north of the depression. This isolated bowl-shaped depression with a diameter of about 600 m and a maximum depth of 40 m looks quite interesting owing to its size, shape and occurrence in isolation (Figures 2 and 3). Wall of the depression has a slope varying from 7° to 20°. The circular structure shows truncated cone shape in the cross section of sub-bottom profile. The slope of the upper walls of the structure is 5–7° and that of the lower parts of the wall in the cross section is 18–20° (Figure 4). The slope of the upper part is gentler in the north eastern half of the circular depression. The depression identified is the largest one ever reported from continental margin of India and seems unique. The isolated occurrence, large size and smooth disc

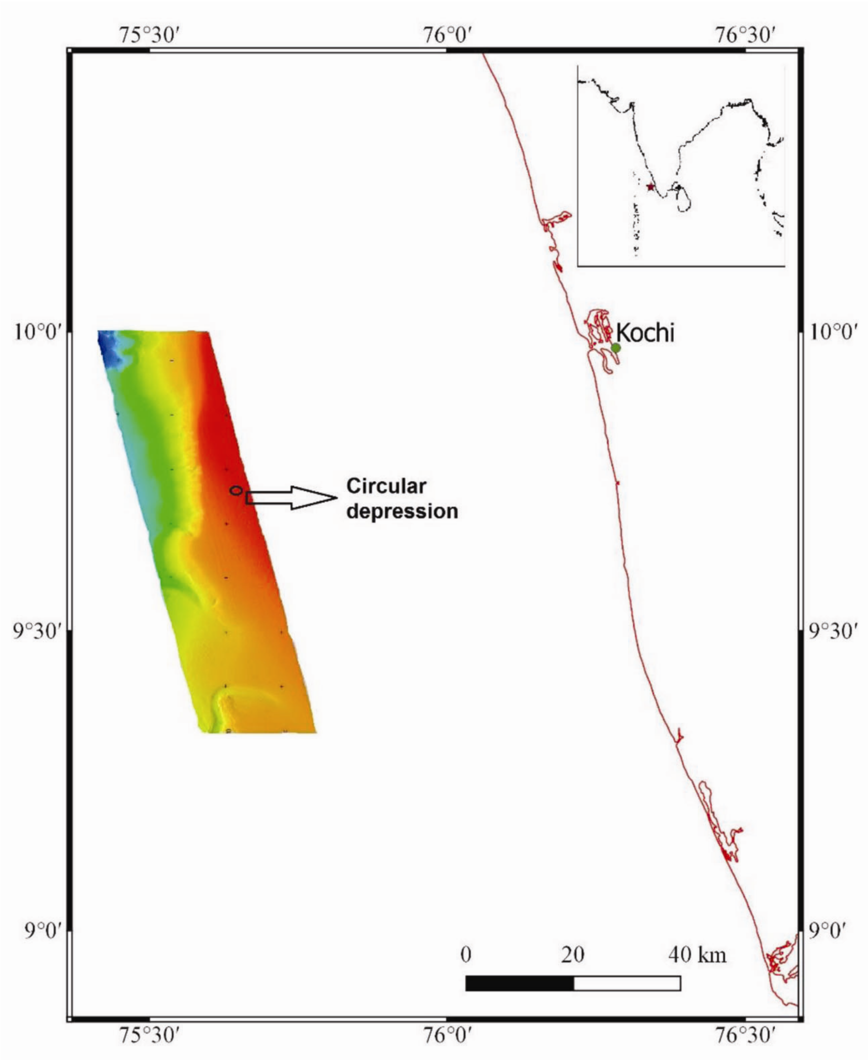

Figure 1. Location of circular depression within the survey area off the Cochin coast, Arabian Sea.