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Publication Date

2023-12-11

Peer reviewed

BERKELEY LAB

Lawrence Berkeley National Laboratory

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Energy Technologies Area

August, 2016

Acknowledgments:

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Office, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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ABSTRACT

Selecting a high albedo (solar reflectance) waterproofing layer on the top of a roof helps lower the roof's surface temperature and reduce the air conditioning energy consumption in the top floor of a building. The annual energy savings depend on factors including weather, internal loads, and building operation schedule. To demonstrate the energy saving potential of high albedo roofs, an apparatus consisting of two nearly identical test chambers (A and B) has been built in four Indian climates: Chennai (hot & humid), Bangalore (temperate), Jhagadia (Hot & dry) and Delhi (composite). Each chamber has well-insulated walls to mimic the core of an office building. Both chambers have the same construction, equipment, and operating schedule, differing only in roof surface. The reinforced cement concrete roof of Chamber A is surfaced with a low-albedo cement layer, while that of Chamber B is surfaced with a high-albedo water proof membrane (change in solar reflectance of 0.28). The experiment will be carried out for one year to explore seasonal variations in energy savings. Initial results in the month of July (post summer) shows that savings from high albedo roof ranges from 0.04 kWh/m^2/day in temperate climates, to 0.08 kWh/m^2/day in hot & dry climate.

Introduction

A high albedo ("cool") waterproofing layer on the top of a roof has benefits to the building and to the environment. It helps to lower the roof's surface temperature and reduce the air conditioning energy consumption in the top floor of a building. When implemented over a city level it mitigates the Urban Heat Island effect, reduces and offsets green-house gas emissions, and improves air quality. The benefits of cool roofs in a building level depends on parameters including location, orientation, shading by trees or other buildings, construction, insulation, plenum ventilation, equipment load, occupancy, and operational schedule (Konopacki & Akbari, 2001). Several studies (Akbari, Bretz, Kurn, & Hanford, 1997; Bertz, Akbari, & Rosenfeld, 1998; Parker, Cummings, Sherwin, Stedman, & McIlvaine, 1994; Levinson & Akbari, 2010; Xu, Sathaye, Akbari, Garg, & Tetali, 2012) have been performed to demonstrate the benefits of cool roofs. It is difficult to correlate the energy savings observed from these studies, since the parameters of the experiments differ; for instance, the window area of the test buildings might be different from one experiment to another.

To demonstrate the energy saving potential of high albedo roofs, an apparatus consisting of two nearly identical test chambers is proposed. Both chambers will have the same type construction, equipment and operation schedule. The reinforced cement concrete roof of Chamber

A will be surfaced with reinforced cement concrete (initial albedo of 0.30), while that of Chamber B will be surfaced with a high-albedo membrane (CertainTeed Flintlastic® SA Cap CoolStar™; initial albedo of 0.58). Apparata (pairs of test chambers) have been constructed in four different climatic zones, as shown in Figure 1. The four cities where the test huts are constructed are Delhi (composite), Jhagadia (hot & dry), Bangalore (temperate), and Chennai (hot & humid).

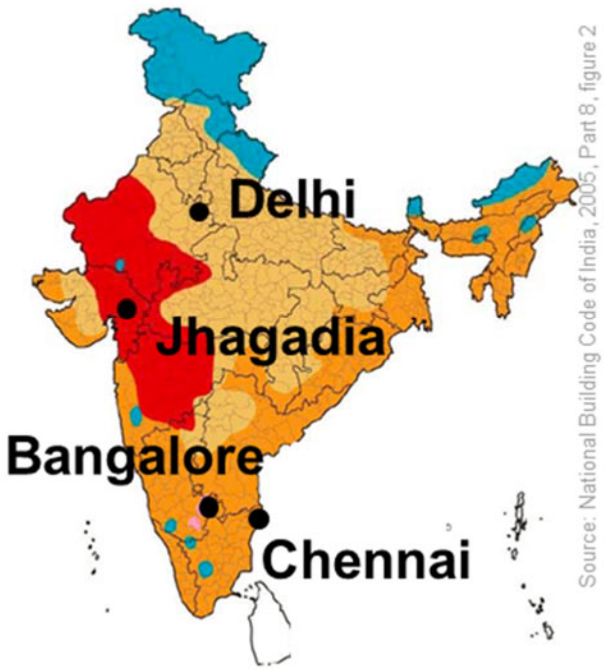

Figure 1: Locations of cool roof test apparata in India

These test chambers mimic a room inside a core zone of an office building as shown in Figure 2. In a conditioned building there will be minimal heat flow between the rooms that are maintained at the same temperature. Therefore, the chamber walls need to be insulated to make wall heat gain much smaller than roof heat gain.

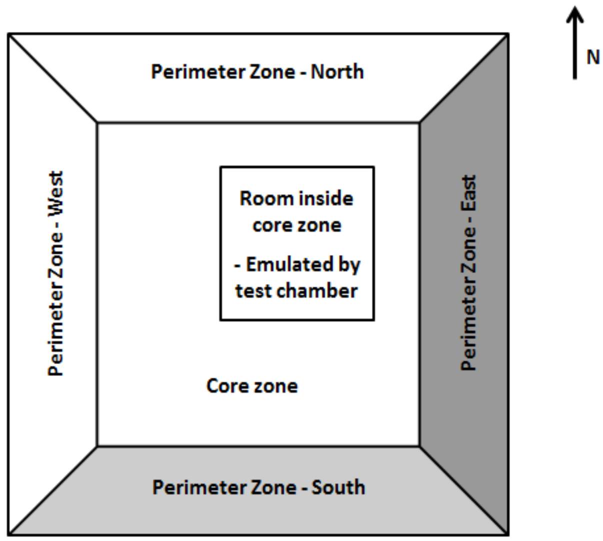

Figure 2: Core + perimeter zoning of a building

Chamber design

The construction details and other parameters used for the simulation are summarized in Figure 3 and Table 1

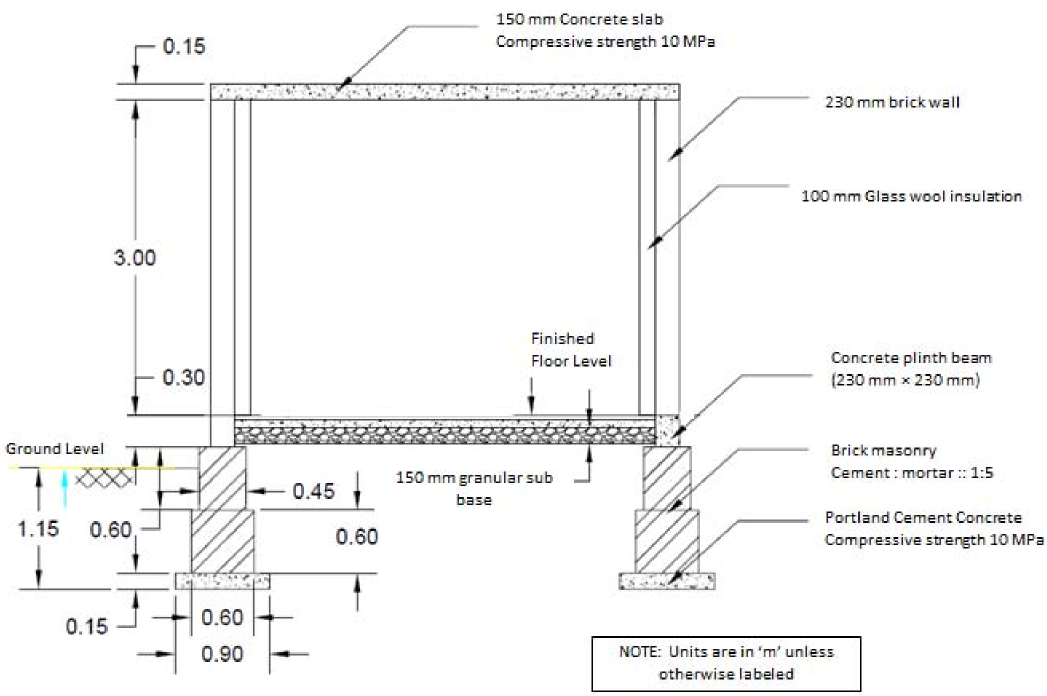

Figure 3: Side cross-section view of a proposed test chamber

Table 1: Chamber A and Chamber B operation details

Building footprint (m × m)	3 × 3
Floor to ceiling height (m)	3
Operation hours (local standard time)	Mon – Sat, 09:00 – 17:00
Occupancy heat load per person (W)	120
Equipment load (W)	240
Lighting load (W)	90
Cooling set point	20°C

Table 2: Chamber A and Chamber B construction details

	Layer #	Layer name	Thickness (mm)	Thermal conductivity (W/m·K)	Thermal resistance (m^2·K/W)
Wall assembly					3.51
Outermost layer	1	Cement plaster with sand aggregate with white wash (SR – 0.60)	25	0.72	0.035
	2	Brick wall	230	0.75	0.31
	3	Glass wool insulation (density 48 kg/m3)	100	0.03	3.12
Innermost layer	4	Cement plaster	25	0.72	0.035
Roof assembly					0.28
Outermost layer	1	Cement finish	25	0.72	0.035
	2	Reinforced cement concrete with 2% steel	150	0.70	0.21
Innermost layer	3	Cement plaster	25	0.72	0.035
Flooring					0.46
Outermost layer	1	Sand filling	150	0.72	0.21
Innermost layer	2	Portland Cement Concrete layer	75	0.30	0.25

Table 3: HVAC system details for Chamber A and Chamber B

<table>
<tr><td>Property</td><td colspan="2">Chamber A & Chamber B</td></tr>
<tr><td>HVAC system</td><td colspan="2"></td></tr>
<tr><td>Air conditioner</td><td colspan="2"></td></tr>
<tr><td>Make and model</td><td colspan="2">Voltas SAC 12 V DY Split AC</td></tr>
<tr><td>Estimated COP (Wh/Wh)</td><td colspan="2">3.0</td></tr>
<tr><td>Nominal cooling capacity (kW) [ton]</td><td colspan="2">3.5 [1.0]</td></tr>
<tr><td>Heating</td><td colspan="2"></td></tr>
<tr><td>Make and model</td><td colspan="2">Voltas SAC 12 V DY Split AC</td></tr>
<tr><td>Nominal heating capacity (kW)</td><td colspan="2">1.0</td></tr>
<tr><td></td><td>Cooling</td><td>Heating</td></tr>
<tr><td>Type</td><td>Split system air conditioner</td><td>Electrical resistance heater</td></tr>
<tr><td>COP</td><td>3.0</td><td>1.0</td></tr>
<tr><td>Capacity (kW)</td><td>3.5</td><td>1.0</td></tr>
</table>

Equipment

The sensors that are used in the experiment are detailed in Table 4. The locations of the sensors are shown in Figure 4.

Table 4: List of equipment used in the experiment

Measurement(s)	Sensor(s)	Location(s)
Outdoor air temperature and Relative humidity	Onset THB-M002	One top of weather station location on the roof of Chamber B
Global horizontal solar irradiance	Onset LIA-M003	
Weather station data logger	Onset HOBO U30	
Outdoor surface temperatures	Linear circuits thermistors	Outside surface of all four walls and roof of Chamber A and Chamber B
Indoor surface temperatures	Linear circuits thermistors	Indoor surface of all four walls and roof of Chamber A and Chamber B
Indoor air temperatures	Linear circuits thermistors	Located in the middle of Chamber A and Chamber B
AC energy consumption	Continental Control Systems LLC Watt Node Logger WNC-3Y-208-FT10 pulse counter transducer with split-core current transformers (CCS, CTS Series)	AC incoming energy wire in Chamber A and Chamber B
Data logger	Campbell Scientific CR1000	Common for Chamber A and Chamber B, located in Chamber B

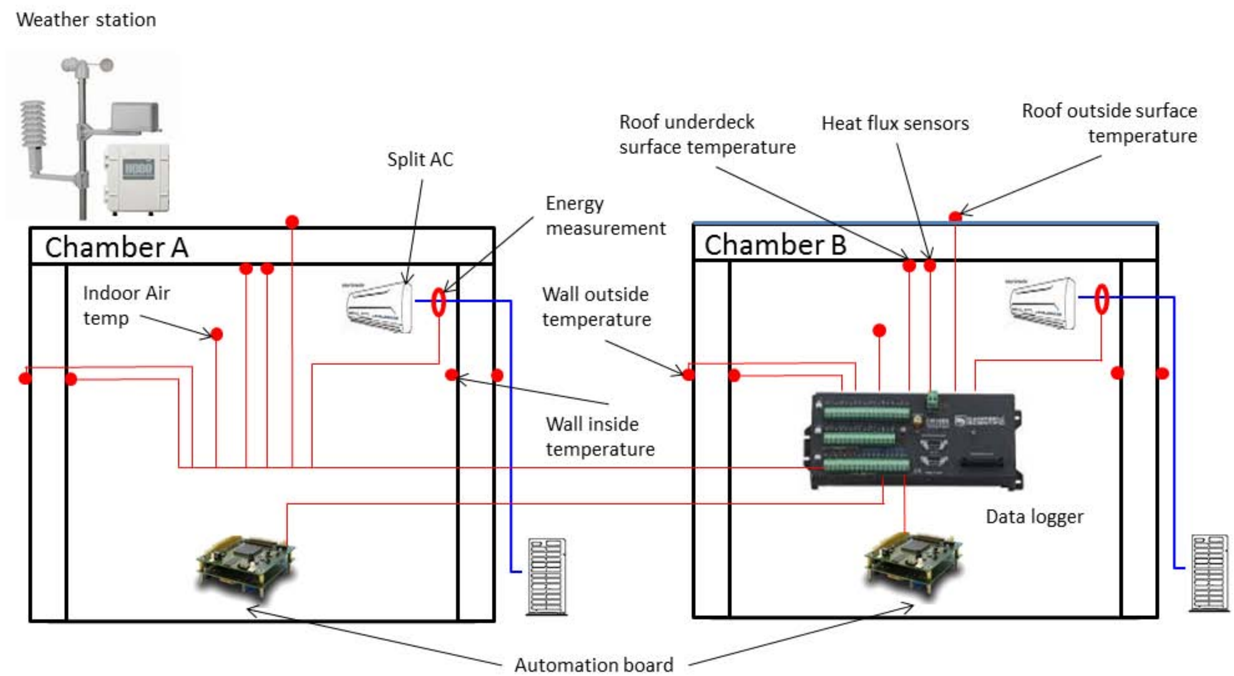

Figure 4: Sensor locations in test chambers

Each Chamber has the same set of sensors and they share a common data logger and weather station. The data will be logged from all the sensors for every 5 minutes. The monitoring experiment is designed in 3 phases

Phase 1: Chambers A and B will have the same low-albedo ('warm') roofing membrane. This period will be used to observe and minimize any differences between chambers in temperature, heat flux, and energy use.

Phase 2: The warm roofing membrane on Chamber B will be replaced with a cool roofing membrane. This period will be used to assess the reductions in temperature, heat flux, and conditioning (cooling + heating) energy use attained by increasing roof albedo (cool roof vs. warm roof).

Phase 3: The warm roofing membrane on Chamber A will be replaced by a fresh cool roofing membrane and the cool roof on top of Chamber B will be replaced with fresh cool roof. This period will be used to assess the reductions in temperature, heat flux, and conditioning (cooling + heating) energy use attained by increasing roof albedo (new cool roof vs. aged cool roof).

Results

The twin chambers were calibrated against each other in each location (Phase 1). The scatter plot of daily energy consumption (Figure 5) of the test chambers in Chennai shows a linear correlation with a slope of 0.94 and a coefficient of determination (R^2) of 0.99. This indicates the consistency of data and near identical behavior of the test chambers. Similar behavior was observed in the other locations.

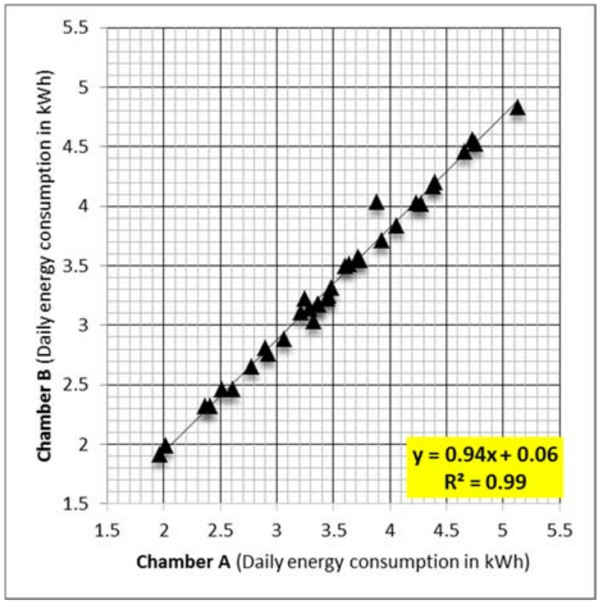

Figure 5: Scatter plot of daily energy consumption of test chambers in Chennai (hot & humid) in Phase 1 (calibration)

After calibration, a high albedo membrane (initial solar reflectance 0.58) was installed over the concrete surface (initial solar reflectance of 0.30). The daily energy consumption of the test chambers before and after installation of cool roofs reduced significantly. In the hot & dry climate (Jhagadia), the energy consumption of Chamber B with the cool roof was lower by 0.08 kWh/m^2·day as seen in Figure 6.

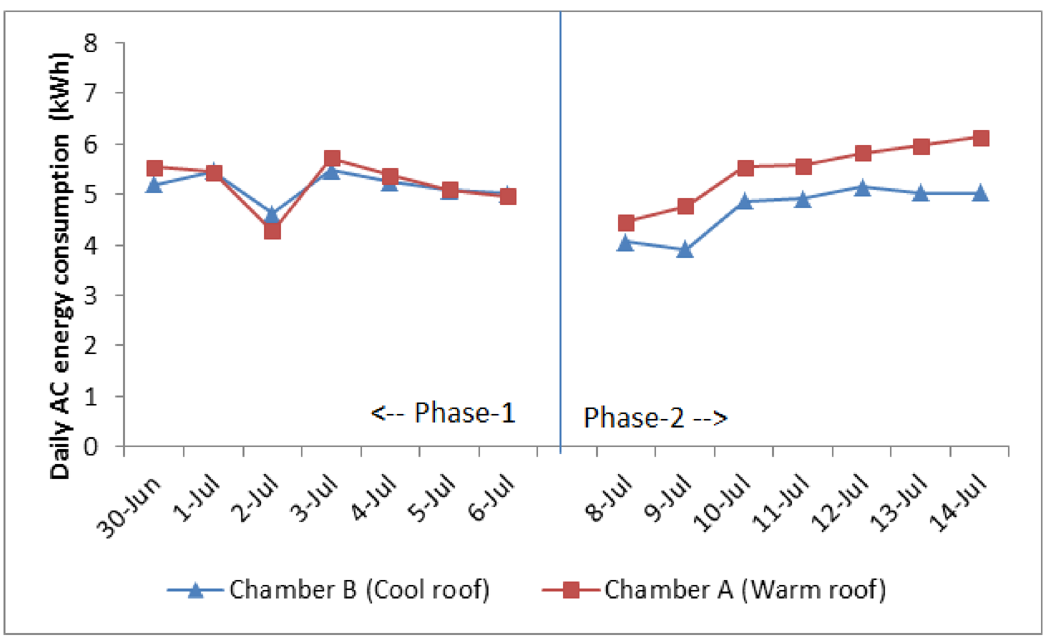

Figure 6: Daily energy consumption of test chambers in hot & dry climate of India

In the temperate climate (Bangalore), the energy savings is lower than in the hot & dry climate (Jhagadia). The energy consumption of Chamber B with the cool roof is 0.04 kWh/m^2·day lower as compared to a warm roof (Figure 7).

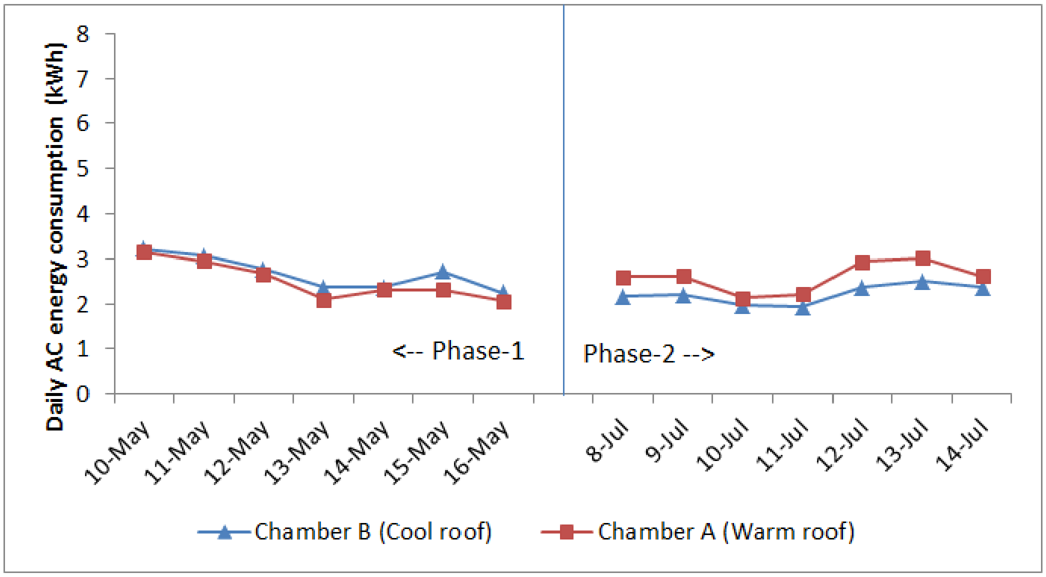

Figure 7: Daily energy consumption of test chambers in temperate climate of India (Bangalore) in Phases 1 and 2

In the hot & humid climate (Chennai), the energy savings from the chamber with the cool roof in similar to that of the hot & dry climate (Jhagadia). The chamber with the cool roof consumes 0.08 kWh/m^2·day less energy when compared with the chamber with the warm roof, as seen in Figure 8.

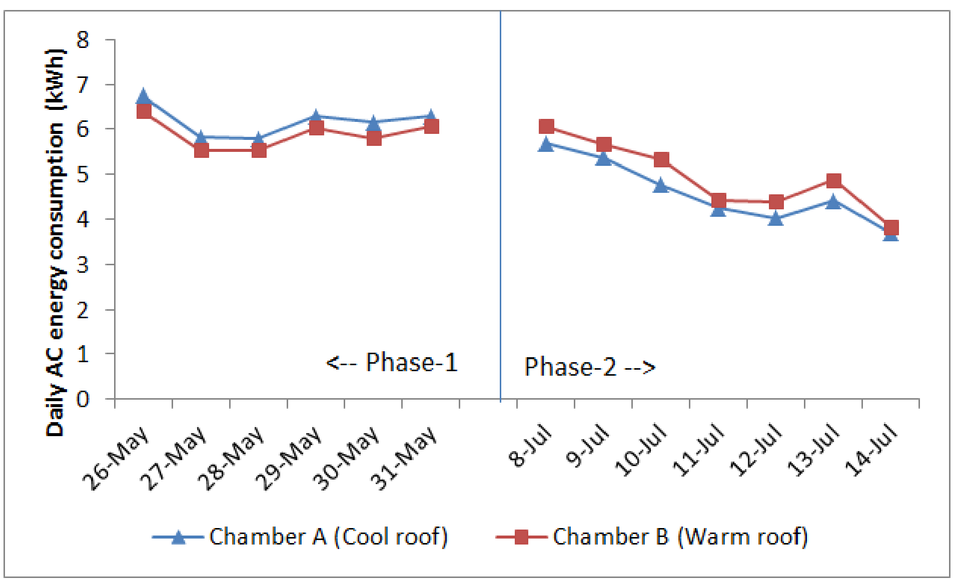

Figure 8: Daily energy consumption of test chambers in hot & humid climate of India (Chennai) in Phases 1 and 2

Summary

A test apparata has been developed to test the performance of high albedo surfaces. It has been constructed in four different climatic zones. Using this apparata we can compare the performance of the same high albedo surface in four different climatic zones.

Acknowledgement

This work was supported by Joint Clean Energy Research and Development Center (JCERDC) for buildings called Center for Building Energy Research and Development (CBERD) funded by the Indian Ministry of Science & Technology, and U.S. Department of Energy and administered by Indo-US Science and Technology Forum in India.

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