

# Advancing Building Energy Efficiency Research in India

Part 1 of 2

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## Introduction

Today, one of the most pressing issues for the building industry is the concern for energy consumption. The building construction sector contributes significant amounts of energy use to the global total, and therefore any realistic attempt to address growing energy use must include measures to make building construction and operation more efficient.

Currently, commercial and residential sectors account for about one third of the electricity used in India. In the next twenty years, these sectors will add twice and thrice the amount of new floor space, respectively, of what currently exists. In addition, residents of India will be continuously increasing their daily use of energy intensive devices, which will further add to the energy intensity and lead to increased amounts of energy used in the country.

The government of India is working to fight climate change, and in this effort has launched a national energy conservation building code, which requires new commercial buildings to meet minimum energy performance criteria. However, considering the large existing building stock, which is already contributing to substantial energy use, and the relatively long lifespan of buildings, it is imperative that measures to increase energy efficiency go beyond incremental increases focused only on the future building stock.

Finally, with growing expectations for thermal comfort, India is currently witnessing a rise in the use of artificial air conditioning, which requires sealed buildings. This demands attention to health and productivity, since the current standard of construction does not adequately address ventilation, except through manually operated openings.

## Research, Education and Industry Collaboration: CARBSE in Context

In the context of pressing energy concerns for the future, a relatively ignorant building industry already using a significant amount of India's overall energy, and increased user expectations for thermal comfort and energy use, any effort in understanding

## About the Author

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*continued on page 52*

*continued from page 50*

energy efficiency in India must work toward a multi-pronged approach to address this multifaceted issue. In the building industry, there is a gap in the knowledge of building material and building performance in India, both at the academic and the professional level. While there is ample knowledge available outside India, very little is applicable in India, both because its climate and latitude differ from the locations in which materials are typically characterized, and its building stock is made from a very different process of construction than what has been documented. India not only needs data on how materials available here perform in this climate, but it also needs tools appropriate to the method of construction that exists here.

The Center for Advanced Research in Building Science and Energy (CARBSE) at CEPT University, Ahmedabad has uniquely positioned itself in the Indian context to work as a node among the networks that comprise the building profession. Its objective is to generate knowledge contextual to India, which entails research on the demand side of buildings and cities, building physics, modeling, and lab and onsite testing, combining scientific rigour with traditional wisdom, to aid in the creation of physical environments.

CARBSE also participates in the creative educational environment at CEPT University. The Centre works as an interdisciplinary hub, drawing on the expertise of academicians from multiple faculties, and providing a platform for students and scholars from diverse majors. Aligned with its research is CARBSE's effort to build capacity through outreach both within and outside the university. The research conducted at the facility feeds into both undergraduate and graduate courses. Beyond just student and academic interaction, CARBSE has the goal of making its work accessible to architects, engineers and other professionals, and using its location within the university as a means to share knowledge both from practice and research, so that academicians and professionals both may benefit. CARBSE provides a platform for visiting scholars, trains professionals, conducts webinars, and works to disseminate findings from its research via website, journals and magazines available to Indian professionals.

CARBSE collaborates extensively with industries through professional training programs, material database development and commercial product testing services for insulation and fenestration materials. The establishment of its capabilities has helped CARBSE to provide support for uniform implementation of the energy code in the building sector in India developed by the Bureau of Energy Efficiency (BEE). In all pursuits, the Centre follows international best practices.

### **Building and Material Testing and Characterization Infrastructure**

To support its research pursuits in the building construction industry, CARBSE has an extensive infrastructure. CARBSE's capabilities can broadly be categorized in two areas: thermal characterization and optical/visual characterization. Almost all procedures are carried out in accordance with ASTM, EN, NFRC or ISO. Presently, CARBSE has capabilities to characterize the following parameters of building materials and components:

#### **Thermal Characterization**

- Thermal Conductivity to derive R-Value and U-Value
- Thermal Diffusivity and Specific Heat

### **The Center for Advanced Research in Building Science and Energy (CARBSE) at CEPT University**

CARBSE carries out in-depth research in the fields of energy efficient buildings and city design and operation, energy efficient building construction processes, environment friendly construction materials and resource audit and management. This research is supported by extensive work to create an infrastructural facility that characterizes thermo-physical-optical properties of building materials, their assemblies and building components, uses a full scale test bed for comparative simulation and on site measurements in whole building envelope performance, and tests HVAC and lighting systems for post-occupancy evaluation. Along with this targeted approach laboratory, the Centre carries out research in building technologies and building energy simulated both digitally and physically, and uses its research to inform policy at the state and national level in India. These aims, combined with efforts in capacity building and outreach, all come together in the Centre's ongoing project for a Living Laboratory, a Net-Zero Energy Building that will house its state-of-the-art testing facilities, working as a platform for building and building component performance evaluation, and knowledge dissemination. It is envisaged that this demonstration building will act as living laboratory for research and development in the areas of building energy efficiency, thermal comfort modeling, day-lighting and low energy cooling technologies. The research facilities here can serve more than just Indian interests. With the most advanced facilities east of Turkey and south of China, CARBSE aims to be a resource for energy efficiency throughout Asia.

- Air Leakage of fenestration products
- Hygrothermal Characterization
- Post-occupancy Evaluation for a building's indoor environment and energy performance
- U-factor and Solar Heat Gain Coefficients of fenestration and wall assembly products

#### **Optical/ Visual Characterization**

- Transmittance, Absorptance, Emittance and Reflectance of glazing materials
- Reflectance of thermal mirrors (non planar surfaces)
- Daylight Performance of building in various sky conditions
- Sun Shadow Analysis

The infrastructure capabilities to produce these results are outlined individually by equipment type.

#### **Hygrothermal Characterization Facilities**

CARBSE employs hygrothermal test facilities, which employ three types of test for material characterization. The first determines the sorption isotherm, the second derives water vapor transmission, and the third quantifies water uplift characteristics due to capillary action. The material properties derived from these tests help in calculating the water content of building materials subjected to various temperatures, pressures and RH conditions. Such characterization aids the understanding of moisture migration occurring in opaque building assemblies, which impacts structural

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continued from page 52

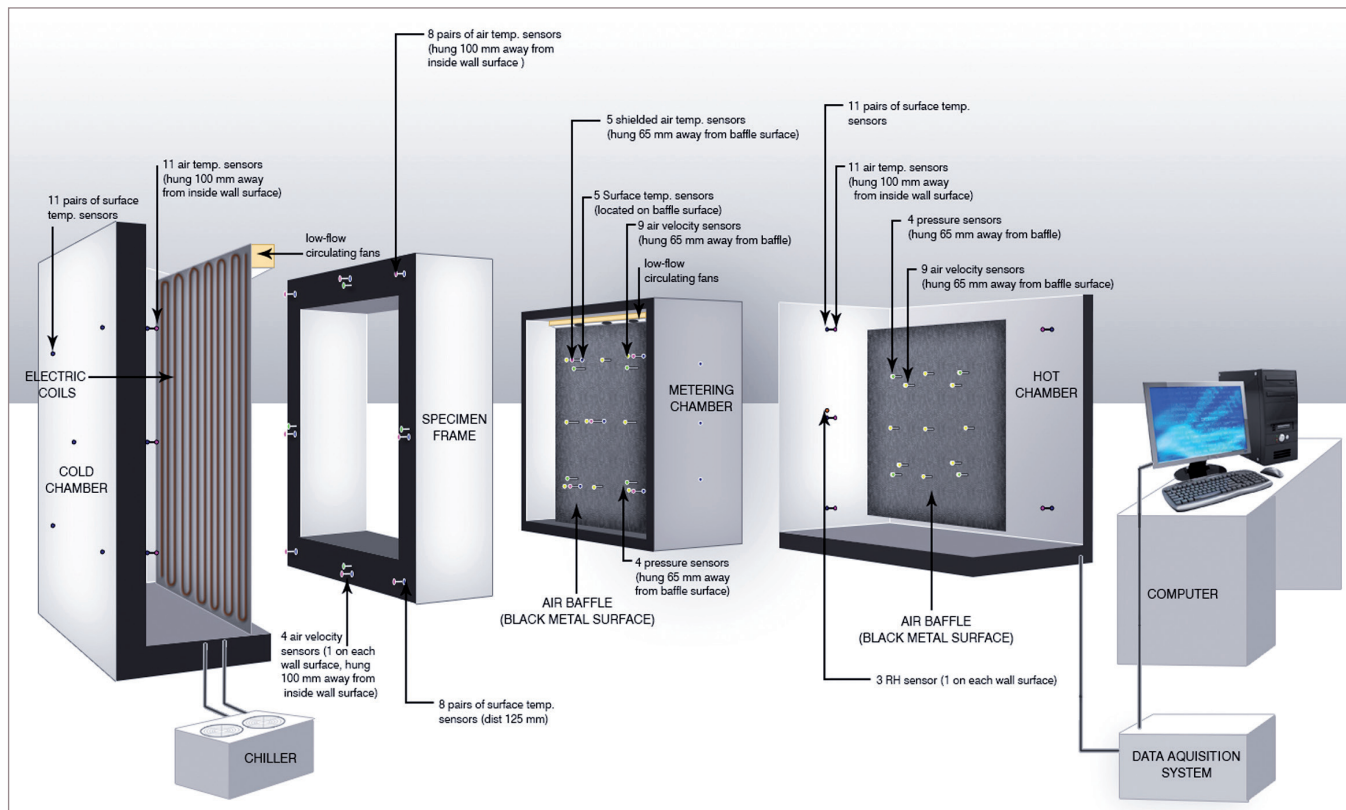


Figure 1: Guarded hot box

stability, indoor air quality and energy demand for the maintenance of desired indoor conditions.

**Solar Calorimeter**

The solar calorimeter measures the solar gain through fenestration products. This is the fundamental test by which solar gains through the window assembly of any such components can be measured. It can also be used for the measurement of the solar efficiency of photo voltaic cells used in Solar PV panels. The solar calorimeter is an insulated enclosure designed to permit the continuous introduction and extraction of a measured flow of fluid mass and equipped with an empty aperture into which a fenestration system is inserted for characterization. The main components of this equipment include room side metering chamber, guard chamber, surround panel for installing test specimen, calibration panel, heliostat and enclosure.

**Guarded Hot Box**

A Guarded Hot Box is used to test the thermal performance of non-homogenous specimens, such as complex wall assemblies, cavity walls, ventilated shaded wall assembly or walls with phase change materials. It determines the amount of heat transfer through a given material or assembly of various materials. This is done by controlling the temperature on both sides of the material and minimizing the extraneous heat transfers other than those through the given material, which can be used to determine the thermal transmittance of homogenous as well as non-homogenous specimens, and can test a specimen with a maximum thickness of 350mm. The metering chamber is cooled using cooling and the guard chamber is maintained at the same temperature using an HVAC system. The climatic chamber is maintained at a higher

temperature using electric coils. Surface, water and air temperature sensors for temperature control along with humidity (RH), pressure, and air velocity sensors are placed at equal distances.

**Heat Flow Meter**

At CARBSE, thermal conductivity characterization is done with two methods: steady state and transient measurement. Using the heat flow meter, which measures thermal conductivity of insulating materials, it is also intended to measure enthalpy as well as the active range for phase change materials. The thermal conductivity of a specimen is determined by measuring the heat flux, specimen thickness and temperature difference across the specimen. Materials tested range from polyurethane foam, insulating industrial material, EPS, XPS, Glasswool and Rockwool. Specimens sized 600mm x 600mm and of thicknesses up to 200mm are characterized for the thermal conductivity range from 0.01 W/m.K to 0.2 W/m.K.

Coupled with another instrument, the heat flow meter can work as per transient method. It can characterize thermal conductivity, thermal diffusivity and specific heat capacity for material in solid, liquid, powder and paste forms. It can measure temperatures ranging from a cryogenic 10 K to almost 1000 K.

**Spectro-photometer and Fourier Transform Infrared Spectrometer (FTIR)**

Solar spectral reflectance is measured using a spectro-photometer equipped with a 150mm integrating sphere. This is a photometer (a device measuring light intensity) that measures intensity as a function of colour (wavelength) of light. It provides the facility for characterization of optical properties of glazing materials, and of systems relevant to energy transfer in flat specular glazing materials. The glazing may be monolithic, coated, with

continued on page 56

*continued from page 54*

applied film, or laminated. The solar absorptance, reflectance and transmittance of a material are determined using both the spectrophotometer and integrating spheres. For glazing materials, optical properties are measured for UV/Vis/NIR spectral range, and solar reflectance for opaque building materials is measured for solar reflectance index (SRI) calculation. Reflectance and transmittance at various angles of incidence can also be measured with the Angular Tubes Spectrometer Accessory, which is useful for flexible and thin materials like shade fabrics.

The emissivity of glazing and cool roof material is measured in Infra Red (IR) range (approximately 1300-44000nm) by a Fourier Transform Infra Red Spectrometer (FTIR), which collects spectra based on measurements of the coherence of a radiative source, using time domain or space domain measurements of the electromagnetic radiation, or another type of radiation. It can be applied to a variety of types of spectroscopy. It is able to compare the ability of a surface to emit radiant energy with that of a black body at the same temperature and of the same area. This equipment is useful for calculating the SRI of cool roofs and cool roof products.

One of the research projects to be carried out through the use of the FTIR is the study of accelerated and natural aging of roofing materials. For accelerated aging, reflectance and emittance is characterized before and after soiling agents are applied to the surface. For the study of natural aging, materials are left exposed for a period of approximately five years, and characterized for reflectance and emittance every three months.

### **Air Leakage Chamber**

The Air Leakage Chamber is used to determine the air leakage rates of windows, doors and curtain walls. It is modified for the requirements of each type of assembly tested, and helps evaluate the relative performance of various fenestration products. Air leakage characterization helps improve performance of air conditioned, mixed mode and naturally ventilated buildings.



*Photo 1: Air leakage chamber*

### **Energy and Indoor Environment Audit Systems**

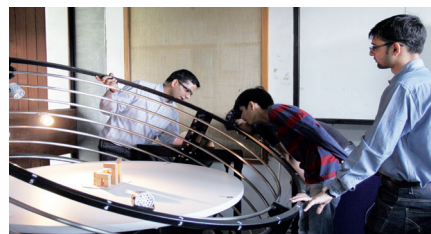
CARBSE also has a range of energy and indoor environment audit systems, which are used in monitoring the performance of existing buildings. Each tool measures aspects of temperature and humidity, air velocity, and light, and some measure multiple criteria. Its micro weather station, with a four-sensor data logger, uses a network of smart sensors to take measurements, which helps in multi-channel monitoring of micro-climates. The micro-sensors measure temperature, RH, rain, wind speed and direction, soil moisture, solar radiation and photosynthetic active radiation;



*Figure 2: The mirror box*



*Photo 2: Artificial sky*



*Photo 3: A heliodon - an artificial sky modeling tool*

Resistance Temperature Detector Sensors (RTDs) measure surface temperature, and can be used to study the thermal performance of materials, and thermal lag of a building. An IR thermometer, for non-contact temperature measurement, determines an object's surface temperature by measuring the amount of infrared energy radiated by the object's surface. The universal light meter is used for conducting post-occupancy evaluation studies, daylight penetration studies and need for electric light and related energy usage in conditioned environments.

Indoor air quality meters are capable of logging as well as taking instantaneous measurements for environmental parameters. These are useful for conducting Post Occupancy Evaluation studies as well as in determining user perceived thermal comfort standards. The Air Velocity Meter gives an accurate air velocity measurement, by simultaneously measuring temperature and velocity. It calculates volumetric flow and actual velocity, and is also capable of measuring relative humidity and CO or CO<sub>2</sub>. Stand-alone data loggers monitor temperature, humidity, and luminance both inside and outside buildings, over long periods of time, at regularly defined intervals. CO/CO<sub>2</sub> can also be measured with an additional probe. The Heat Stress Wet Bulb Globe Temperature (WBGT) meter measures and displays heat stress index, which describes how hot it feels when humidity is combined with temperature, air movement, and direct or radiant sunlight.

### **Building Technology Simulation and Testing Facilities**

Post-occupancy evaluation and building performance monitoring hold important roles in understanding the existing condition of the building stock, identifying areas for improvement, and addressing issues that can be retrofitting to improve energy efficiency. But along with these goals, data acquired stands to hold great value in improving the design process for future buildings, where larger gains in efficiency can be implemented, because of more informed design decisions, and the possibility for more gradual or radical change. For that reason, CARBSE works to put its data to use in developing simulation tools, both digital and physical, which test various building technologies, and advance their potential as systems within both existing and new construction projects. The development of online tools, sky simulators and thermal comfort chambers will be made available to practitioners, and can give designers valuable information to feed into their design processes.

### **Daylight Studies Using Mirror Box, Single Patch Sky Simulator**

Daylight, when used correctly, can work to improve energy efficiency in buildings through the controlled admission of natural light, both direct and diffused, into a building. This can reduce electric lighting and save as much as one third of total building energy costs. Day-lighting cannot be accomplished simply by allowing sunlight to enter the building. The introduction of daylight into the interior space must be optimized according to the program of the space, and must also respond to the dynamic patterns of outdoor illumination. But

*continued from page 56*

in doing so, designers using daylight have the opportunity to create a visually stimulating and productive environment for building occupants that transforms throughout the course of the day. Toward this end, CARBSE is developing a mirror box and a single patch sky simulator, which can produce artificial sky conditions.

The CARBSE mirror box will be used to simulate overcast sky conditions for building models, to help architects and engineers understand day-lighting inside a building and take necessary steps to increase building performance and reduce energy consumption for artificial lighting. The mirror box consists of an extremely bright homogeneously lit ceiling and mirrored walls. The light source is a milky white diffusing acrylic sheet illuminated from behind with over 10,000 LEDs. The mirrors, arranged vertically all around the periphery of the box, produce an image of the lit ceiling by reflection and inter-reflection to infinity, which accurately simulates a perfectly distributed overcast sky. The mirror box generates light levels between 12,000 and 15,000 lux on work plane placed in the center of the box, at the bottom edge of the mirrors, which replicates the situation of a perfectly flat and clear horizon. A building model to be analyzed for day-lighting is placed inside the mirror box and illuminance levels are measured using a lux meter.

CARBSE's Single Patch Sky Simulator complements the mirror box. The system consists of a turntable, mirror and Fresnel lamp. By emulating one sky patch out of the total 145 virtual divisions with equal area of the sky dome, as per Tregenza's model, a building model placed on a turntable can be rotated so that the lamp is directed from each of the sky dome's 145 divisions, and illuminance

levels can be taken. These measurements are then aggregated so that they accurately reflect the daylight performance of the space under the whole sky dome. The advantage of this is that because the measurements are taken according to 145 patches, once measured physically only once, the effective sky can be altered to simulate any sky condition simply by adjusting the weightage of individual patches, and calculating the effect on the building's luminance levels.

### **Thermal Comfort Chamber**

The Thermal Comfort Chamber (TCC) is a chamber sized 6m x 5m x 3m, which can precisely simulate a wide range of indoor environmental conditions with temperatures ranging from 15°C to 40°C and relative humidity from 16% to 95%, along with changing air distribution patterns and speed. This particular capability is useful for Indian studies because it allows researchers to measure the impact of air velocity, a necessary criteria in a context dependent on the use of fans for cooling. These conditions are maintained and monitored by sophisticated air conditioning systems and control devices. The purpose of the TCC is to conduct experiments to evaluate the impact of various indoor environmental conditions on occupant comfort, productivity and well-being. People participating in the research would sit on four workstations in the TCC and experience thermal conditions set by the research team. ❖

*Part 2 of this article, to be published in the November-December 2014 issue, will cover a snapshot of research activities and a description of the Living Laboratory, a Net Zero Energy Building.*