PNNL-19487

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

India's R&D for Energy Efficient Buildings: Insights for U.S. Cooperation with India

S Yu
M Evans

June 2010

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

DISCLAIMER

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

This document was printed on recycled paper.
(9/2003)

PNNL-19487

India's R&D for Energy Efficient Buildings: Insights for U.S. Cooperation with India

S Yu
M Evans

June 2010

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

India's national research and development (R&D) programs are managed primarily by the Department of Science and Technology (DST) and affiliated science and technology councils. Currently, under the 11th Five-Year Plan (2007-2012), India has developed the National Energy Efficiency R&D Plan and a related National Energy Fund (NEF). Building energy efficiency, solar energy and solid state lighting (SSL) are included as research priorities. The Council of Scientific and Industrial Research (CSIR), as the manager of India's national laboratories, also identifies its research priorities through national R&D programs. The national R&D program includes work on commercialization and market transformation mechanisms. In terms of international collaboration, India is actively participating in International Energy Agency's (IEA) implementing agreements on demand-side management, and building and community systems. There are also bilateral collaborations with the European Union, United States, China and other nations.

This report outlines India's current activities and future plans in building energy efficiency R&D and deployment, and maps them with R&D activities under the Department of Energy's Building Technologies Program. The assessment, conducted by the Pacific Northwest National Laboratory in FY10, reviews major R&D programs in India including programs under the 11th Five-Year Plan, programs under the NEF, R&D and other programs under state agencies and ongoing projects in major research institutions[1].

The United States and India have several parallel areas of research. The Indian Government has placed priority in its R&D program on solar energy and SSL. In addition, India has multiple programs to deploy energy-efficient building technologies in both the residential and commercial sectors. India's R&D priorities are linked to its social, climatic, and energy circumstances, as India has large rural areas in hot climates that lack basic power supply.

Based on India's priorities and the current research portfolio of the U.S. Department of Energy, SSL, solar energy and cool roofs appear to be ripe for collaboration. Research on technology integration and deployment also lend themselves to cooperation, given the mutual benefits and the limited intellectual property concerns.

[1] For a list of these institutions, please refer to Appendix A.

Acronyms and Abbreviations

APP	Asia Pacific Partnership on Clean Development
BEE	Bureau of Energy Efficiency
BEL	Bharat Electronics Limited
CBRI	Central Building Research Institute
CSIR	Council of Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
DST	Department of Science and Technology
ECBC	Energy Conservation Building Code
GOI	Government of India
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
IIT	Indian Institute of Technology
LED	Light Emitting Diode
MNRE	Ministry of New and Renewable Energy
MoU	Memorandum of Understanding
NEF	National Energy Fund
NTPC	National Thermal Power Corporation Limited
OLED	Organic Light Emitting Diode
R&D	Research and Development
RGGVY	Rajiv Gandhi Grameen Vidyuktikaran Yojana
SERC	Science and Engineering Research Council
SITAR	Society for Integrated Circuit Technology and Applied Research
SSL	Solid State Lighting
TERI	The Energy Research Institute
TIFAC	Technology Information, Forecasting and Assessment Council

Contents

Figures

1.0 India's National Strategies in Building Research and Development (R&D)

1.1 Overview of Building Energy Consumption in India

India has seen significant economic growth in recent years. In 2007, the gross domestic product reached $1.1 trillion on a nominal basis (IMF 2008). At the same time, energy consumption has also increased quickly. India was the fifth largest energy consumer in 2006, and its carbon emissions account for 4.4% of the global total that year (EIA 2008).

The construction industry is a major economic driver in India, adding about 22 million square meters of commercial buildings and 19 million square meters of residential buildings between 2004 and 2005 (Mathur 2006). Currently, commercial buildings are the third largest consumers of energy in India after industry and agriculture. Buildings annually contribute to more than 20% of the electricity used in India (Confederation of India Industry 2009). Figure 1.1 illustrates the energy consumption of different appliances in Indian buildings.

The potential for energy savings in new buildings is 40-50% if energy efficiency measures are included in the design stage. For existing buildings, the potential could be as high as 20-25% after energy efficiency retrofits (Confederation of India Industry 2009).

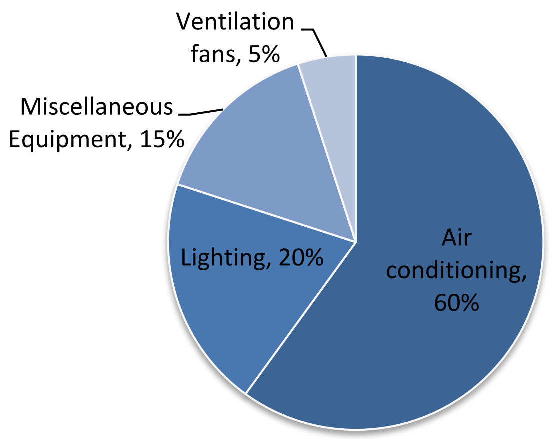

Figure 1.1. Breakdown of Energy Consumption in Indian Buildings (Confederation of India Industry 2009)

Demand for office space in India is driven by the growth of the service sector. A conservative estimate of the rate of increase in office space in India is approximately 55 million square feet/year (Mathur 2007).

Most commercial buildings in India have an energy performance index ranging from 200 to 400 kWh per square meter per year compared to less than 150 kWh per square meter per year in North America and Europe. Large-scale, energy-efficient building design is limited due to a split incentive – builders fear that they would bear the costs while tenants would enjoy benefits (Mathur 2007). Energy consumption in the commercial building sector is 5.6% of total energy consumption (Misra 2006).

1.2 India R&D Structure

The Council of Scientific and Industrial Research (CSIR) is the main body in India for research and development (R&D). Currently, there are 37 National Laboratories and 38 field Centers under CSIR, including the Central Building Research Institute (CBRI) located in Roorkee (Department of Scientific and Industrial Research, Ministry of Science and Technology 2010) .

The Department of Science and Technology (DST) plays a lead role in identifying and promoting priority areas of R&D in various disciplines, and produces a working group report on R&D based on the Five-Year Plans. The Science and Engineering Research Council (SERC) acts as an advisory body consisting of eminent scientists and technologists that contributes to DST's priority setting. The Science and Technology Advisory Committees sets up formulation of joint technology development programs for the 24 socio-economic ministries.

DST has set up an autonomous body, the Technology Information, Forecasting and Assessment Council (TIFAC), to prepare technology forecasts, assessments, and market surveys. TIFAC previously carried out a program called "Technology Vision for India up to 2020" to provide insights to the government in setting national science and technology initiatives. DST has also built other facilities to facilitate R&D such as the Center of Relevance and Excellence and the Patent Facilitating Center.

Other research institutes and consultants in India include the Energy Research Institute (TERI), the Center for Environmental Planning and Technology, the Indian Institute of Technology-Bombay (IIT-Bombay), the Ministry of New and Renewable Energy's Solar Energy Center, and the Bharat Heavy Electricals Corporate R&D Center[1].

1.3 National Programs of Building-Related R&D

In the 11th Five-Year Plan (2007-2012), the objective of the energy efficiency R&D program is to "enable, develop, and support the testing and marketing of energy-efficient products and their adoption in enterprises and households". The strategic approach is to create "consortia of product developers and product users together with organizations that can provide the research and engineering skills necessary to develop/upgrade products". The national program would support the incremental costs of product development and product developers and users would bear the majority of costs and reap the benefits of it (Office of the Principal Scientific Advisor 2006a).

The national program focuses on the following areas: energy-efficient buildings and building components (such as energy-efficient windows, low-cost insulation materials, and simulation software) and energy-efficient appliances (such as energy-efficient ceiling fans, very low-energy consumption circuits for stand-by power, and low-cost light emitting diodes (LED)-based lamps).

[1] For details of respective institutes, please refer to Appendix A.

In 2001, the Government of India (GOI) created the Bureau of Energy Efficiency (BEE) to institutionalize the promotion of energy efficiency and building energy efficiency. BEE focuses on deployment, which can help commercialization.

The TERI, with sponsorship from HSBC bank, is preparing a comparative study on global building benchmarks that will identify gaps and establish potential areas for R&D investment in various technologies and Indian specific standards (TERI 2009).

1.4 Funding

The GOI sets up a National Energy Fund (NEF) to finance R&D on energy and energy efficiency. In the 11^{th} Five-Year plan, the NEF commissions and funds energy-related R&D in 13 areas, including building energy efficiency and LED. The fund is to support a range of collaborations between institutions in India and to set up research Center of Excellence focused on energy technologies (Planning Commission GOI 2008).

The NEF levies a tax (at least 0.4% of turnover of a company) on all companies engaged in primary and secondary energy production with annual turnover above Rs. 1 billion (about $25 million[2]). Eligible contributions to the NEF qualify the participating company for tax deductions (Planning Commission GOI 2008).

Under the 11^{th} Five-Year Plan (2007-2012), the NEF budgeted Rs. 2.05 billion (about $50 million) in energy efficiency R&D and an additional Rs. 10 billion (about $250 million) in LED R&D. In energy efficiency R&D, the GOI will use Rs. 1.3 billion (about $325 million) in the building sectors including Rs. 0.50 billion (about $12.5 million) for buildings and components, and Rs. 0.80 billion (about $20 million) for appliances (Office of the Principal Scientific Advisor 2006a).

Product developers and users would bear basic costs of product development and deployment in pilot buildings. The R&D program would support costs for testing, the incremental costs of the adoption in pilot buildings, and the costs of monitoring, evaluation and training (Office of the Principal Scientific Advisor 2006a). The NEF also provides funding to promote the formation of consortia between industry, research institutes, and academia in each priority R&D area.

[2] The calculation here and below is based on the exchange rate USD/INR=40.

2.0 Current R&D Programs and Activities for Buildings

Currently, most activities to improve energy efficiency in residential and commercial buildings focus on deployment. The programs underway, either in national plans or through international collaboration, are to identify policies, measures, techniques, and programs to make energy-saving retrofits in existing buildings, and to better implement energy conservation technologies in new buildings. There are also efforts collaborating with the Asia Pacific Partnership on Clean Development and Climate (APP) to harmonize test procedures of appliances.

The R&D activities focus primarily on LED and solar energy. These activities are not listed in the building category but as separate programs under the 11th Five-Year Plan. The Jawaharlal Nehru National Solar Mission is a long-term national program, from 2009 to 2022, to advance solar energy R&D in India. India also has few R&D activities on energy efficient appliances – ceiling fans and standby power.

2.1 Solid State Lighting

2.1.1 Background

Currently, India has several national programs to provide solid-state lamps to villages. The Lighting a Billion Lives program, a collaboration of TERI and the Asian Development Bank, is to develop new methodologies and approaches, and to support demonstration projects that are scalable and replicable and/or designed to lead to large-scale programs that will have significant long-term impacts on increasing household access to energy. The project aims to provide access to lighting facilities to about 1500 households, which translates to reaching 30-40 villages.

Domestically, the National Thermal Power Corporation Limited (NTPC) is planning to electrify and adapt SSL-based lamps in thousands of villages in the next five years under the Rajiv Gandhi Grameen Vidyuktikaran Yojana. The plan is to deploy tens of millions of solid-state lamps.

2.1.2 LED/OLED R&D in General

Key Stakeholders: Office of the Scientific Advisor to the Government of India, NTPC, Society for Integrated Circuit Technology and Applied Research (SITAR), and Bharat Electronics Limited (BEL).

Background and Current Problems: India, at present, is more successful in system-level development with imported LED chips, whereas wafer manufacturing is only at the research level addressing very limited issues of wafer fabrication. The LED chips are imported primarily from the United States and Taiwan, and Kwality Photonics Pvt. Ltd., Hyderabad, is one of the private companies involved in this. . BEL is also interested in setting up a facility to manufacture white spectrum LEDs in the country. In 2007, BEL and CREE signed a Memorandum of Understanding (MoU) for cooperation in this area.

Research focus: During the 11th Five-Year Plan, the R&D program would seek to bring together manufacturers of lamps and luminaries, lighting engineers, and building developers to develop a wide variety of luminare-lamp configurations and to test the lighting performance of these prototypes in pilot buildings.

The NTPC and SITAR are contemplating establishing a vertically integrated LED manufacturing facility in India to avoid importing processed wafers and to form a joint venture company to launch production of LEDs and SSL lamps. However, they have not disclosed whether the manufacturing facility would use Indian or licensed technologies.

Funding: The NEF LED program will budget 10 billion (about $250 million) to develop and commercialize core LED and OLED technologies, and set up a LED manufacturing facility in the country (Office of the Principal Scientific Advisor 2006a). In addition, the NEF energy efficiency program will budget Rs. 100 million (about $2.5 million) to develop, install, and test the energy-efficient lighting systems.

Source: Office of the Principal Scientific Advisor 2006a.

2.1.3 Fabrication of LED Devices and Systems for Solid State Lighting Applications

In CSIR's R&D plans, there are several activities related to SSL research. Fabrication of LED devices and systems is one of priorities in the electronics, photonics and instrumentation area. Functional organic materials for energy-efficient devices, described in the next section, are one of priorities in the energy resource and technology research area.

Principal investigator(s): National Physical Laboratory, New Delhi; Central Electronics Engineering Research Institute, Pilani; Central Scientific Instruments Organization, Chandigarh; Regional Research Laboratory, Trivandrum; Indian Institute of Chemical Technology, Hyderabad; Central Building Research Institute.

Research focus: To develop technology for the growth of gallium nitride material and fabrication of LED devices using the grown material to develop prototype SSL sources.

Envisaged outcomes/outputs:

- III-V epilayers on suitable substrates with defined specifications
- Growth of high-quality doped epitaxial multi-layers
- Deposition of organic multi-layers suitable for OLED
- LEDs of defined specifications
- Development of standards (measurement protocols)
- Development of suitable display, automotive and lighting systems for direct applications.

Source: Office of the Principal Scientific Advisor 2006b.

2.1.4 Functional Organic Materials for Energy-efficient Devices

Principal investigator(s): Regional Research Laboratory, Trivendrum; National Chemical Laboratory, Pune; Central Leather Research Institute, Madras.

Background: Various chemical laboratories of CSIR have been involved in the synthesis of conjugated conducting polymers materials that may find uses in photonic, electronic and optoelectronic devices. The objective of the proposed work is to develop novel, functional organic materials, dyes, and photochromic systems that can be used for a variety of photonic and electronic applications such as photovoltaic devices, LEDs, imaging systems and optical memory discs, and optical switches.

Research Focus: To develop novel functional organic materials, dyes and photo-chromic systems, for use in a variety of photonic and electronic applications such as photovoltaic devices, light emitting diodes, imaging systems and optical memory discs and optical switches.

Envisaged Outcomes/Outputs: Development of functional organic materials, dyes, and photochromics for photonic and electronic applications.

Source: Office of the Principal Scientific Advisor 2006b.

2.1.5 Mapping to the U.S. Department of Energy's Building Technology Program Multi-Year Project Plans

To understand potential synergies between Indian and U.S. R&D on building energy technologies, we have mapped Indian R&D to the priority tasks listed in BTP's Multi-Year Project Plans (MYPPs). The results are summarized in the table below.

United States[1]	India
LED Priority Product Technology Tasks for 2009	
Epitaxial Growth	Fabrication of LED Devices and Systems for Solid State Lighting Applications: *III-V epilayers on suitable substrates with defined specifications *Growth of high-quality doped epitaxial multi-layers
Other Identified LED Product Development Tasks	
Yield and Manufacturability Manufacturing Tools	During the 11th Five-Year Plan, the program would seek to bring together manufactures of lamps and luminaries, lighting engineers, and building developers to develop a wide variety of luminare-lamp configurations and to test the lighting performance of these prototypes in pilot buildings. The lighting performance of the high-quality, low-cost lamps would be disseminated through training programs to architects and lighting engineers.
Smart Controls	Fabrication of Led Devices and Systems For Solid State Lighting Applications Development of suitable display, automotive, and lighting systems for direct applications
OLED Priority Core Technology Tasks for 2009	
Novel Materials	Functional Organic Materials for Energy-efficient Devices Development of functional organic materials, dyes, and photochromics for photonic and electronic applications
Others	
Others	India focuses on independent manufacturing facilities and mass production for rapid increase in supply. However, wafer manufacturing is only at research level addressing very limited issues of wafer fabrication. To pursue joint R&D and technology transfer, the GOI signed an MoU with Cree but details of the collaboration were not released.

[1] DOE. "Multi-Year Program Plan FY'09-FY'15: Solid-State Lighting Research and Development." (Internal working document).

2.2 Building Envelopes and Windows

India has engaged in research activities on Phase Change Materials (PCMs) for some time. Although there is little recent public data on research activities and tasks, India does produce PCMs. There was an extensive demonstration project on PCM-based thermal storage system for building air conditioning at Tidel Park, Chennai.

Although not listed clearly in the program, India tends to have strong interest in cool roofs due to its largely tropical areas. In 2007, the United States Agency for International Development worked with IIT-Hyderabad on this topic; there is a testing program in Hyderabad to demonstrate the effectiveness of cool roofs in India.

India also uses solar energy technologies in building envelopes to improve building energy efficiency. These include the development of concepts of solar/green buildings (e.g., green walls, smart windows) and the development of test protocols and design of test set-ups.

In terms of windows, the GOI did not identify specific technologies in its national program. It listed the activities and targets in general: develop, test, and adopt energy-efficient windows. The program would support product testing and the adoption of prototypes in pilot buildings together with monitoring and evaluation of their operating effectiveness. Information on the performance of the products would be widely disseminated among potential users (architects and developers) to promote greater adoption of efficient windows. NEF plans to allocate Rs. 220 million (about $5.5 million) to the development of low-cost insulation (Office of the Principal Scientific Advisor 2006a).

2.3 Solar Energy

2.3.1 Background

India is endowed with vast solar energy potential. About 5,000 trillion kWh per year of solar energy is incident over India's land area with most parts receiving 4-7 kWh per square meters per day (MNRE 2009). However, solar energy use in India has been constrained by cost, availability of space, and effective storage.

Under the 11th Five-Year Plan and Jawaharlal Nehru National Solar Mission (2009-2022)[2], solar energy became of the focus of a major R&D initiative of the GOI and state governments. Solar energy in buildings is one of the major applications. The long-term goal of solar energy research is to create conditions, through rapid scale-up of capacity and technological innovation, to drive down costs towards grid parity. The 11th Five-Year Plan emphasizes deployment of solar energy applications in the following areas: solar passive architecture, solar thermal systems/devices, solar water heating, and renewable energy and energy-efficient buildings.

[2] For details, please refer to Appendix B.

2.3.2 National Solar R&D Program in India

R&D Aim: To accelerate on-going R&D efforts on different aspects of solar energy technologies with the objectives of improving the efficiency and system performance, and reducing the cost.

R&D thrust areas include:

- Development of storage systems (including molten salts with lower freezing temperatures and PCMs)
- Development of heliostats with automatic tracking controls
- Development of advanced solar systems for cooling (space cooling, cold storage, and refrigerators)
- Development of other solar thermal applications (i.e. innovative designs for solar cooking, solar air heating, and drying applications) (Kumar 2010)

2.3.2.1 Tasks

Low-temperature Applications

Solar cooling: Design and development of a solar air conditioning system for residential applications. The target cooling capacity is 5-10 kW with a coefficient of performance (COP) of 0.6 or higher. Design and development of a double effect absorption chiller driven by high-efficiency concentrating solar collectors for institutional applications. The capacity of these systems could be 15 kW and higher. The target COP is 1.2 or higher.

Solar thermal materials/devices: Development of advanced glazing for windows for industrial production in the country. Development of advanced selective coatings suitable for applications in the temperature range of 300 - 600 degrees C. Development of polymer-based, low-cost materials for various solar thermal applications.

Testing, Certificate and Code

Ensure the introduction of an effective mechanism to certify and rate manufacturers of solar thermal applications. Make solar heaters mandatory through building bylaws and incorporation in the National Building Code. Support the upgrading of technologies and manufacturing capacities through soft loans to achieve higher efficiencies and cost reductions.

A greater thrust is required to develop standards, testing, and certification of solar thermal systems. Such standards need to be referenced under in the ECBC, where applicable.

2.3.2.2 R&D Activities in Solar Energy Center, Ministry of New and Renewable Energy

Below are the R&D projects, which the Ministry of New and Renewable Energy's Solar Energy Center (MNRN n.d.) is responsible for. Since the date is not indicated by the center, some projects below might be complete.

- Tools for architectural design and simulation: An integrated approach to building design. (IIT, Bombay).
- Energy plantation for production of biomass for power generation (Phase-II) (National Botanical Research Institute (NBRI), Lucknow).
- Design, development, and testing of a low-temperature solar desalination system (TERI).
- Development of light emitting diode -based Solar Photovoltaic lighting systems.
- Development of a reference solar cell, reference modules, and calibration facilities.
- Performance monitoring of Solar Energy Center greenhouse (TERI).
- Development of software and hardware for measurement of M-Factor and correcting photovoltaic cell parameters to standard reporting conditions or other conditions. (IIT, Delhi)
- Solar, optical, and thermal modeling and measurement of energy flow at different nodal points of 50 KW solar power plants at the Solar Energy Center. (IIT, Delhi)
- Establishment of computer software for detailed design and specifications of solar water heating systems in India. (IIT, Delhi)
- Thermal performance of flat plate collector "Evaluation and Updating of Indian Standards." (IIT, Delhi)
- Development of a transient test procedure for characterizing solar flat plate collectors. (IIT Bombay)
- Development of test standards for thermal performance of solar cookers. (IIT, Delhi)
- Status report on renewable energy operated desalination system. (TERI, Delhi)
- Application of finite-time thermodynamic and second law assessments of solar thermal power generation. (IIT, Delhi)
- Development of evaluations of SPV power packs and farm equipment. (India Agricultural Research Institute, Delhi)
- Establishment of a spectral response measurement system. (Indian Association of the Cultivation of Science, Calcutta)
- Design and cost optimization techniques for solar hybrid absorption refrigeration plants using second law analysis and exergo-economics. (IIT, Delhi)
- Development of a mechanical load test system for PV modules. (National Physical Laboratory, Delhi)
- Round-robin testing of flat plate solar collectors and box type solar cookers in India. (IIT, Delhi)
- Development of design, guidelines, and preparation of handbook on energy conscious architecture, (IIT, Mumbai)
- Energy plantation for production of biomass for power generation (Phase-1), (NBRI, Lucknow)

2.3.3 Solar Cooling for Urban and Remote Rural Applications

With financial support from MNRE, TERI started a project in April 2009 to develop a combined solar biomass based cooling system. The system is designed for village-level cool storage with electricity supply applications, and for urban residential/office space cooling applications.

MNRE, GOI, and the Government of Australia and Sustainability Victoria, Australia are jointly financing this project. The project implementers include TERI, MNRE's Solar Energy Center and Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), with Thermax India and Rannie Australia serving as industry partners.

2.4 Energy Efficient Appliances

2.4.1 Ceiling Fans

India is the largest producer and user of ceiling fans. The current technological platform, based on an induction motor-capacitor system, is reaching the limits of efficiency as measured in terms of volumetric airflow delivered by the fan for each watt of electrical power.

During the 11^{th} Five-Year Plan, the R&D program will focus on the development and testing of alternate technological platforms (based on DC motors or linear motors for energy-efficient ceiling fans). The program will bring together a consortium of ceiling fan manufacturers and R&D institutions to develop and test a range of prototypes based on advanced electric power technologies combined with electronic power management systems. Reliable and robust prototypes would be further supported for long-term monitoring and evaluation of tests. NEF will budget Rs. 500 million (about $12.5 million) for the development and testing of energy-efficient ceiling fans.

2.4.2 Standby Power

Under 11th Five-Year Plan, India initiated R&D on standby power. To address the increasing use of standby power in offices and households, the program would develop low-cost electronic circuits that reduce the standby power demand of office and household appliances to less than 0.5 watt. In addition, a consortium of manufacturers and R&D organizations would design and test the energy performance and long-term reliability of advanced circuits, which would have low energy consumption. The NEF plans to budget Rs. 500 million (about $12.5 million) to develop appliances and circuits with low standby power demand (Office of the Principal Scientific Advisor 2006a).

3.0 Conclusions

India has a well-developed R&D infrastructure. Several institutes conduct research on energy efficiency in buildings, including CSIR, TERI and IIT. The national building research program focuses more on deployment programs rather than new technology R&D, but at the same time, there are ongoing R&D programs to develop new SSL and solar energy technologies.

India's SSL research includes programs on new materials, controls and manufacturing processes. Indian institutions have also begun to build manufacturing capacity for LED products. The market for LED products in India has grown considerably, a trend facilitated by large government procurements.

The Indian government also has a national mission on solar energy research that includes building-related solar technologies. India's climatic conditions favor the use of solar energy in buildings, which creates a large potential market for solar energy installations. Currently, there are national and state programs working on deploying solar energy technologies, with additional programs proposed. Indian R&D on solar energy focuses on storage systems, advanced systems for cooling and other solar thermal applications like solar cookers.

There are many synergies between Indian and U.S. research on building energy technologies. Both countries work on deployment programs and conduct research on ways to build markets for these technologies. While the U.S. has a broader suite of R&D programs on building energy technologies, both countries have active programs on SSL and solar energy. These areas of synergy may create fertile ground for collaboration on technology deployment mechanisms and new technology development.

4.0 References

AFC Consultants International. "India: Energy Efficiency New Housing." AFC Consultants International. (accessed January 14, 2010).

APP. 2009. *Project Roster - Buildings & Appliances Task Force.* http://www.asiapacificpartnership.org/english/pr_buildings_appliances.aspx#BATF_Project_40 (accessed January 14, 2010).

Confederation of India Industry. 2009."Energy Efficiency in Building Design and Construction." New Delhi, India.

Energy Information Agency (EIA). 2008. World Carbon Dioxide Emissions from the Consumption and Flaring of Fossil Fuels, www.eia.doe.gov/emeu/international/carbondioxide.html, (accessed January 2009).

Evans, M, B Shui, and S Somasundaram. 2009. *Country Report on Building Energy Codes in India*. Richland, Wash: Pacific Northwest National Laboratory.

IMF. 2008. World Economic Outlook Databases, www.imf.org/external/ns/cs.aspx?id=2, January 2009, (Accessed).

Just, T, M Vath and H Chin. 2006. *Building up India: Outlook for India's Real Estate Markets*. Frankfurt am Main, Germany: Deutsch Bank Research.

Kumar, A. 2010. *Solar Thermal Technology Research and Development*. New Delhi, India: MNRE.

Mathur, A. 2006. *Current Status of Energy Efficiency Building Codes in India.* www.iea.org/textbase/work/2006/buildings/mathur.pdf (accessed January 20, 2010).

Mathur, A. 2007. "Energy Conservation Building Code: An Overview." WEC-IMC Energy Synergy Dialogue.

Misra, S. 2006. *Operational Framework to Promote Energy Efficiency in Building Codes*. http://wwww.iea.org/work/2006/buildings/misra.pdf (accessed January 19, 2010).

MNRE. 2009. *Jawaharlal Nehru National Solar Mission - Towards Building Solar India*. New Delhi, India.

MNRN. *Solar Energy Center*. http://mnes.nic.in/sec/sec-activities-ird.htm (accessed January 14, 2010).

Office of the Principal Scientific Advisor. 2006a. "Report of the Working Group on R&D for the Energy Sector for the Formulation of the Eleventh Five Year Plan (2007-2012)." New Delhi, India.

Office of the Principal Scientific Advisor. 2006b. "Eleventh Five Year Plan 2007-2012: Report of the Working Group on CSIR." New Delhi, India.

Planning Commission, GOI. 2008. *Eleventh Five-Year Plan (2007-2012) Volume III: Agriculture, Rural Development, Industry, Services, and Physical Infrastructure*. New Delhi, India: Oxford University Press.

Planning Commission, GOI. 2006. "Integrated Energy Policy - Report of the Expert Committee." New Delhi, India.

TERI. 2009. *Ongoing Projects: Market Study on Energy Efficiency in Buildings*. http://www.teriin.org/index.php?option=com_ongoing&task=details&sid=728 (accessed January 18, 2010).

TIFAC. 2009. *Technology Vision 2020 Exercise*. http://www.tifac.org.in/index.php?option=com_content&view=article&id=36&Itemid=48 (accessed January 19, 2010).

Appendix A

Building-Related Research Institutes in India

Appendix A

Building-Related Research and Deployment Institutions in India

Name	Areas
Central Building Research Institute (CBRI)	Building materials; development of new technologies for the promotion of building materials and systems; transfer of developed technologies to industry for further commercialization. Research and developments in the field of efficiency of buildings have led to climatic zoning of the country for building design, formulation of standards for thermal and visual comfort, wind speed, and lighting levels indoors and evolution of guidelines and methods for designing energy-efficient buildings. Development of devices for solar energy utilization has resulted in commercial exploitation of various types of solar water heaters. An autonomous hybrid PV-thermal system has also been developed for electrical and thermal use in buildings.
IIT Bombay	Solar, zero-energy buildings, heat transfer.
Bureau of Energy Efficiency (BEE)	Building codes and labels.
ICLEI	Sustainability and energy-efficiency projects deployed by local governments; a variety of energy-efficiency deployment program in urban and rural areas.
Center for Environmental Planning and Technology (CEPT)	Openings and fenestration in buildings.
Glazing Council of India (GCI)	Certificating and labeling of envelopes and windows.
ISHRAE (Indian Society of Heating, Refrigerating and Air Conditioning Engineers)	Development and promotion of heating, ventilation, and air conditioning (HVAC) standards and test procedures.
Solar Energy Center, MNES	Solar resource assessment, solar thermal, solar buildings, solar photovoltaics, solar energy materials, solar thermal power generation, interactive R&D, bio-fuels. Technology evaluation, testing and standardization.
Jawaharlal Nehru National Solar Mission	A nationwide mid/long-term research project on solar energy.
The Energy and Resource Institute (TERI)	Energy efficiency research and deployment; green building demonstrations; building energy efficiency, building codes, solar energy, lighting, various deployment programs.
India Institute of Science (IISC)	Alternative building technologies and materials, energy-efficient and environmentally sound technologies; functional efficiency of buildings including climatic-performance, energy, solar architecture; renewable energy; solar, biomass combustion and gasification, biomethanation, bio-fuels, etc.; renewable energy; energy planning, demand side management, energy efficiency.
Bharat Heavy Electricals Corporate R&D Center	Solar lanterns, solar photovoltaics, solar water heating systems, surface coatings, building energy management.

Appendix B

Jawaharlal Nehru National Solar Mission R&D Strategy

Appendix B

Jawaharlal Nehru National Solar Mission R&D Strategy

Jawaharlal Nehru National Solar Mission is a major initiative of the Government of India and State Governments to promote solar energy research, development and deployment. The mission would adopt a three-phase approach, spanning from 2009 to 2022. It would set the long-term and short-term goals for India's solar energy initiatives, which include solar energy R&D in buildings. The mission follow the below strategies in solar energy R&D:

- Research at academic/research institutions on materials and devices with long-term perspective.
- Applied research on existing processes and developing new technologies.
- Technology validation aimed at field evaluation of materials, components, and systems.
- Development of centers of excellence on different aspects of solar energy.
- Solar energy center to be made an apex center of excellence.
- Public-private partnership mode development.
- Support for incubation and innovation.

Industry and research organizations will be encouraged to leapfrog, benefiting from the ongoing research efforts in other countries through i) funding collaborative research involving Indian universities/industry and global institutions, with the benefits of the research accruing to Indian institutions through joint access to the intellectual property right ii) support of contracted research for exclusive use by Indian companies, and iii) buying equity in research companies in select countries.

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

U.S. DEPARTMENT OF
ENERGY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)
www.pnl.gov