Green Retrofit Potential in Existing Research Laboratories and Demonstration of Energy Efficient and Sustainable Technologies: Case Study

Ashok Kumar, Dr. P.S.Chani, Dr. Rajesh Deoliya

Abstract— The increasing desire for better comfort predicts upward trend of future energy demand in existing research laboratories in India and plays a critical role in improving the overall sustainability and efficiency of buildings. The aim of this research is to investigate green retrofit potential with green retrofit measures in existing CSIR laboratories, which will be in function beyond 2050. A series of retrofit strategies are proposed including energy efficient fixtures, and power generation thorough solar energy to improve the performance of a CSIR – CBRI building as case study, which represents a typical research laboratory with spaces for labs, teaching, office, researchers' rooms etc. The results indicate that the proposed retrofits measures not only contribute to about 40-50% energy savings and improve thermal comfort during summer. Similarly, the cost- benefit analyses reveal that although the initial cost of proposed energy retrofits are high but that can be paid back in 5- 10 years in India.

Index Terms— *energy, existing buildings, green retrofit, research laboratories, SPV, unconditioned,*

I. Introduction

The construction of buildings and their operation contribute more than 40 % of the total energy end-use worldwide. The existing buildings exhibit the most severe problems of excessively high energy, poor indoor environmental quality, thermal comfort and low productivity, while the replacement rate of existing buildings by the new-build is only around 1.0 - 3.0% per annum [1] – [4]. The majority of existing buildings that were built before energy crisis, energy efficiency was not a concern at all, and most of these buildings will still be in function until 2050 or beyond. In India, unconditioned buildings form the largest chunk of the existing building stock due to a favourable climate [5]. The concept of demolishing and rebuilding after 20-25 years of operation is not sustainable for the future as it requires extensive amounts of materials that are becoming scarce and wastes the embedded energy of constructing the original building [6]. Therefore, researchers around the world recognized that green building retrofit is one of the main approaches to achieve reduced building energy consumption, greenhouse gas emissions and sustainability in built environment at relatively low cost.

The green building retrofit aims to determine, implement and apply the most cost effective retrofit technologies to achieve enhanced energy performance while maintaining satisfactory service levels and acceptable indoor thermal comfort. Green retrofits are any kind of upgrade at an existing building that is wholly or partly occupied to improve energy and environmental performance, reduce water use, and improve the comfort and quality of space in terms of natural light, air quality, and noise – all done in a way that is financially viable to the owners with payback guarantees [7] – [9]. The ASHRAE [10] describes the high performance green building as a building designed, constructed and capable of being operated in a manner that increases environmental performance and economic value over time [11]. The existing literature shows a good number of research publications on conditioned buildings. Yu Huang *et al.* [1] have proposed a systematic methodology for appropriate retrofits of existing buildings for energy efficiency and sustainability.

A large number of research papers attempt on passive retrofitting to improve the energy performance of buildings [12] – [16]. Researchers have investigated the energy saving potential, the effectiveness and performance of different retrofit measures and systems [17]. Several studies show the potential benefits of roof vegetation, which not only alter the microclimate of building roofs and improve roof insulation but also provide cooling through transpiration of water [18] – [19]; and overall heat transfer coefficients, materials & construction techniques [20] - [22].

Limited are the examples of research on green and energy – efficient retrofitting of unconditioned buildings and hardly any literature on research laboratories. A study on unconditioned academic institute by Nasib and Mathur [23] for National Institute of Technology, Jaipur, India discusses

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Ashok Kumar, *Senior Principal Scientist & Head (Architecture & Planning) CSIR- Central Building Research Institute, Roorkee, India. Tel: +91 1332 283204, +91 9897074178*

Dr. P.S.Chani, *Associate Professor, Department of Architecture & Planning, Indian Institute of Technology, Roorkee, India,*

Dr. Rajesh Deoliya, *Principal Scientist, CSIR- Central Building Research Institute, Roorkee, India*

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the Clean Development Mechanism potential through solar water heaters and solar steam cooking and energy – efficient technologies for air- conditioning and lighting. It does not explore the integration of energy – efficient building envelope. Another study on unconditioned academic institute by A. Sharma *et al.* [5] for a building at Indian Institute of Technology, Roorkee, India explored the integration of energy – efficient building envelope using simulation. The authors have used the available ISHRAE climatic data and materials data, which might be different from the real – time experimental data and the authors, have stressed the need for further research on real – time and experimental studies.

To date, there is no major green retrofit project in India. Hence, this paper explores the retrofitting potential in Council of Scientific & Industrial Research (CSIR) laboratories and demonstrates the green and / or energy retrofits in 66 years old CSIR – Central Building Research Institute (CBRI) laboratory building in use to significantly reduce the use of conventional energy and improve the thermal comfort vis-à-vis performance comparable to that of green and energy efficient buildings constructed according to good green practices by doing the real – time experimental studies.

II. RESEARCH METHODOLOGY

The following methodology is adopted to explain different green and / or energy retrofit scenarios:

a) Reconnaissance survey of CSIR laboratories and field study method to collect data of the reference building as a case study;
b) Energy audit of the reference building and strategies for energy conservation ;
c) Building performance assessment;
d) Rainwater harvesting;
e) Demonstration of Solar Photovoltaic Panels.

III. RECONNAISSANCE SURVEY

The reconnaissance survey of six CSIR laboratories viz; CSIR - Indian Institute of Petroleum (IIP), Dehardun, Central Scientific Instruments Organization (CSIO), Chandigarh, National Physical Laboratory (NPL), Delhi, Central Road Research Institute (CRRI), New Delhi, Centre for Cellular and Molecular Biology, Hyderabad, and Central Building Research Institute (CBRI), Roorkee located in different climatic regions, and built during last 50-70 years, was carried out with a view to understand the generic architectural characteristics, construction practices and energy consumption scenario.

Most CSIR research laboratories are unconditioned with window air-conditioners to satisfy hot-dry, and warm-humid needs. The survey reveals that energy efficiency was not a concern when these buildings were built with burnt clay brick walls and reinforced cement concrete roofs / floors without any roof treatment for thermal protection. The windows are single glazed with plain glass of 3 - 4mm. The energy in – efficient fixtures are used apart from individual air – conditioners. Due to climatic changes, there is a felt need to improve their thermal performances. Hence, there is a need to propose green retrofit strategies for the entire CSIR laboratories located in different climatic regions.

Fig.1. Front view (North – West) of the reference building

To accomplish these objectives, CSIR- Central Building Research Institute, established in 1947, located in the state of Uttarakhand is chosen for detailed analyses, real - time studies and demonstration as a case study (Figure 1.). Major part of India falls in composite climate where heat gain from roofs and walls is a main problem. The diurnal temperature variations are as large as 35 to 22^{0}C. The high summer day time temperature is between 39- 45^0 C, summer time low is27-32 ^{0}C , winter time high temperature is 10-25 ^{0}C, and low 3 -10 ^{0}C with mercury touching around 1^{0}C [9].

The pre-retrofit study of the reference building was carried out in order to know the building operational problems, occupants concerns, indoor environmental quality and the retrofitting potential. The interview responses of several employees on thermal comfort indicate as either satisfactory on ground and first floor during summer. There is a relative increase in number of unsatisfactory conditions during summer, for the employees occupying top floor. However, indoor conditions are reported satisfactory on all the floors during winters. A field study method was used to collect data to identify materials.

A data logger was used to monitor temperature inside and the results reveal that maximum heat transfer takes place from 100mm thick RCC roof without insulation on the two - storeyed block, where the maximum inside temperature observed during June was 38.3^{o}C as compared to outside temperature of 43.0^{o}C. The minimum was observed during January for outside 1.5^{o}C and the inside of 13.8^{o}C. Similarly, in second floor of the building having RCC roof 120mm thick, maximum inside temperature observed during June was 35.5^{o}C as compared to inside on ground floor of 32^{o}C. This is due to thick RCC roof and mud phuska and brick tiles treatment. The minimum inside temperature was observed during January as 17^{o}C. This indicated that heat transfer was more through roof and less in walls due to thermal mass of 345mm thick brick masonry plastered on both sides with 15mm cement mortar.

IV. ENERGY AUDIT OF THE REFERENCE BUILDING

Energy audit was carried out to understand energy use, identify areas with energy wastage, and propose low cost energy conservation measures. The analysis was carried out to: i) create an energy profile of the building including monthly electric and diesel use, total energy consumption;

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ii) compare existing indoor space conditions in terms of function of space, availability of natural light, and ventilation levels, and identify major areas of energy losses; and iii) list retrofit options and carry out cost - benefit analysis.

By proper usage and resetting the thermostat settings at 23 - 26 ^{o}C has reduced 2 hours operation and reduced cooling load of about 20% per day during April 2013 – September 2013. There is a saving of about 0.31kW/Ton by replacing old ACs (Table 2). To further reduce energy losses, operation of the system is proposed to be automatically controlled by putting occupancy sensors that turn off supply of conditioned air while the occupant is not inside the room.

Table 1: Diesel consumption and cost of units generated through DG sets

Description	Number of Units per Hour	Cost 2013 (Rupee)
Total Units generated by DG sets	300	-
Diesel Consumption (2 x 50 liters / hour)	100 liters / hour (3 units/liter)	-
Cost of unit generated by DG sets @ Rs. 51 per liter Diesel	-	Rs. 17.0 per unit
Net cost of unit generated with operation & maintenance	-	Rs. 19.0 per unit

Table 2. Cost Benefit Analysis of Energy Efficient Air- Conditioners

Description	Remarks
Total installed capacity of old AC Units	103 nos.
Annual energy consumption by old air conditioners considering 8 hrs./day and 150 days operation in a year (103 x 1.71 x 8 x 150 kWh)	211,356 kWh
Annual energy consumption by new energy efficient air conditioners operating for 6 hrs./day for 150 days/annum (103 x 1.40 x 6 x 150) kWh	129,780 kWh
Net energy saving	81576 units
Annual cost saving (81576 x 3.93/Unit)	Rs. 3,20,593/-
Average cost of energy efficient Star labeled AC units (1.5 Ton)	Rs. 23,000/-
Total Investment Required for replacing 103 ACs	Rs. 23, 69,000/-

CSIR-CBRI gets power supply through one 1000 kVA transformer and the sanctioned demand is 850 kW. The annual and average monthly energy consumption during 2013 is approx. 18.35 Lakh units and 1.53 Lakh units respectively. The maximum demand reached during the last 5 years is 780 kW. The energy rate including taxes is 3.93 rupees per unit in 2013. Two DG sets of 250 kVA are also installed to feed power at the time of power failure. About 50 liters per hour of diesel is consumed in each set at an electrical average loading of 70-80% (Table 1).The energy efficient fixtures were evaluated from economic point of view [11] and are discussed below.

i) Replacement of existing air conditioners- About 65% of energy is consumed by 103 window and split air-conditioners (ACs) of 1.5 Ton capacity and 2Ton capacity installed at various places. Out of these, 50% are about 15-20 years old and consume more energy. These have been replaced and new energy efficient, 103 ACs installed in the reference building are not only consuming less power but their cooling effect is also improved.

ii) Energy conservation from artificial lighting - Many areas in the building remain unoccupied during the day. Leaving the lights 'ON' when no one is present inside, results in wastage of energy. Hence, it is proposed to install occupancy sensors to avoid wastages and also put up signs (Switch 'OFF'AC & lights while leaving the room for more than 5 minutes) on the inner side of door to remind the occupants while leaving. Such a campaign is already helping to reduce wastage of about 10-12% per day in the building.

iii) *Use improved luminaires by replacing conventional fluorescent lamps*- Presently; energy efficient lamps called T5 lamps with electronic ballast are available. Each lamp consumes 28 ± 1 watts with 20% higher light output of 3000 Lumens and life of 18000 hours. Starter on fitting is not required. The conventional inefficient ballast with 55 watts per lamp (2500 Lumens) has a life of 5000 hours. These lamps can be easily retrofitted with existing installations. The light quality of these lamps produces 80 lm/W and average annual energy consumption is equal to 8.1 kWh/m^2. Electronic ballasts increase the energy efficiency of the lamps and use only 47% of the energy of common ballast. Hence, it is proposed to replace conventional lamps with energy efficient T5 lamps (Table 3).

Table 3. Cost Benefit Analysis of Improved Luminaires

Description	Remarks
Total number of tube lights installed in the reference building	410
Total Power consumption (410 x 55 watts)	22.55 kWh
Total power consumption with T5 lamps (410 x 28 watts)	11.48 kWh
Net power saving with T5 lamps	11.07 kWh
Annual energy saving (Assuming 8 hours operation per day for 260 days) (11.07 x 8 x 260 kWh)	23,025 kWh
Annual Cost saving @ 3.93 per unit	Rs. 90,488/-
Cost of T5 lamp with conversion kit	Rs. 800/-
Total lamps which can be replaced	410
Total Investment Required	Rs. 3,28,000/-

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iv) Replacement of old ceiling fans - Ceiling fans provide desirable levels of air circulation indoors which extend the comfort zone close to 32 °C during summer months. The energy efficient ceiling fans consume only 50 watts where as old fans consume 90-100 watts. Hence, it is recommended to replace existing fans (Table 4).

Table 4. Cost Benefit Analysis of Energy Efficient Fans

Description	Remarks
Total number of old ceiling fans installed in the reference building	160
Total power consumption (160 x 96 Watts)	15.36 kW
Total power consumption with energy efficient ceiling fans (160 x 50 watts)	8.00 kWh
Net power saving	7.36 kWh
Annual energy saving assuming 8 hours operation per day for only 200 working days excluding the cold season (7.36 x 8 x 200) kWh	11,776 kWh
Annual cost saving @ 3.93 per unit	Rs. 46,279/-
Cost of one energy efficient ceiling fan	Rs. 1500/-
Total fans which can be replaced	160
Total Investment Required	Rs. 2,40,000/-

Table 5. Cost Benefit Analysis of Energy Efficient Fans

Description	Remarks
100 KWp Solar PV system complete with modules, Battery Back-up, Mounting Structure & fittings including CST @ 5% (A)	2,62,00,000.00
Installation & Commissioning of Solar PV system (B)	8,00,000.00
Sub Total (A+B)	2,70,00,000.00
Service Tax on above @ 10.3% (C)	27,81,000.00
Total project cost for installation and commissioning (D) = (A+B+C)	2,97,81,000.00
Availability of Subsidy by MNRE, India @ 90%	2,68,02,900.00
Total Investment for CSIR- CBRI, Roorkee	29,78,100.00
Average output achieved during May 7, 2013 till date 70% with maximum reaching 79 % as against 90%.	
Power production with 70% output	70 KWh
9 hours per day (8:00 to 17:00 hours) = 9 x 70	630 KWh
Total production per annum with 75% efficiency	2,29,950 KWh
Payback period (@ Rs. 19/- per unit generated by DG sets)	≈ 7 months

available during daytime, which in turn affects the amount of artificial illumination, cooling and heating loads [10] and [26]. The desirable illuminance indoors for various fenestration percentages requires precise estimate of daylight. For room depths 7.0 m or more, it is desirable to provide windows on opposite walls [27].

V. Building Performance Assessment

The primary requirements of the interior environment in any building are adequate light, ventilation and thermal comfort. The U- values of materials used in reference building were computed using Guarded – Hot Plate method. The Energy Conservation Building Code (ECBC) [24] and National Building Code [25] recommend U- values for roof assembly 0.409 W/m^{2}k and wall assembly 0.440 W/m^{2}k for daytime use buildings and to satisfy the requirements, insulating materials such as Expanded Polystyrene (EPS) and Polyurethane Foam (PUF) are proposed. The brick masonry 345 mm thick with 15mm inside & outside cement plaster has U value of 1.61 W/m^{2}k that may be retrofitted by polyurethane foam insulation of 40mm thick. Similarly, 120mm thick RCC roof with 50mm mud phuska, 50mm brick tiles and 15 mm cement plaster has the U- value of 2.55 W/m^{2}k that can also be retrofitted by polyurethane foam insulation 50mm to comply with the provisions of the codes.

Illuminance measurements for daylight effectiveness'- The size and location of windows affect the amount of daylight

Rooms in reference building have less depth and windows of size 2370 x 1500 mm provide sufficient daylight and facilitate natural ventilation. The room index and illuminance measurement points are taken for a sample room using the following equation:

Room Index (RI) = $(L \times W) / (H_m \times (L + W))$

Where, room length = L, width = W, and H_m = mounting height of the lamp above measurement plane. Minimum illuminance measurement points are determined based on room index for W= 3370 mm, L = 6640 mm, and H_m = 2200mm, and the average value is 1. 01. For RI < 2 and + 5% accuracy, 18 grid points using Lux Meter are shown in (Figure 2) for a typical room of reference building and the average measured value is 169. The Lux level is low in many spaces while windows with venetian blinds / slats are in overlapping position as we move away from perimeter zone. Natural lighting gives 120 - 550 lm/W; 550 lm/W, nearer to perimeter zone and 120 lm/W away from the windows with no venetian blinds as compared to 120 - 130 lm/W reported

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by M. Santamouris *et al.* [12]. This may be due to window size and white paints inside. Hence, it is recommended to use daylight to have sufficient Lux levels indoors as per NBC [25] and install sensors so that artificial lights will remain off while daylight levels are greater near the perimeter zone.

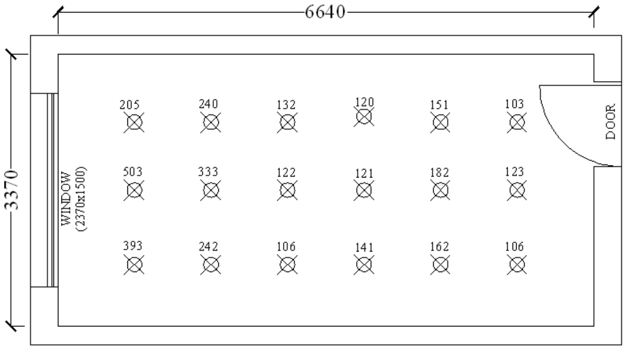

Fig. 2. Grid showing Illuminance Measurements using Lux Meter

The study also shows that windows have an impact of increased solar gains due to 3mm thick glass, U value: 5.29 W/m^2k and solar heat gain coefficient (SHGC) 0.86. Hence, it is proposed to retrofit glass windows with U: 3.30 W/m^2k and SHGC 0.25.

VI. Rainwater Harvesting

The annual precipitation is about 660 mm during the rainy season in Roorkee. For roof top rainwater harvesting, having ground floor covered area of 2568 m^2, one water tank of 3000x4000x2100 mm is required to fulfill the 25.2 KL capacity as per Uttarakhand State Government Regulations. Since there is a large landscape area around the building that requires continuous irrigation, a reduction in water use can be achieved by: i) using pervious surfaces and use of native vegetation; ii) recycled water from rainwater harvesting tanks; and iii) by using low - flow plumbing fixtures with 50% reduced water consumption viz; wash basin, cistern, and sink with sensors.

VII. Demonstration of Solar Photovoltaic Panels

Ministry of New and Renewable Energy, Government of India, gives 90% subsidy for solar energy use for Uttarakhand state. The criteria considered for study was to identify best orientation, tilt and distance between the panels i.e. the shading effect. In terms of orientation, eastern, south – eastern, and western surfaces with greater potential to accumulate solar radiation were considered. Rooftop was selected for Solar Photovoltaic (SPV) panels' integration as the most appropriate and cost – effective choice to have shadow free and flat surface. CBRI is the first research laboratory of CSIR to implement the technology followed by Indian Institute of Petroleum, Dehradun, both in the state of Uttarakhand, India.

Fig. 3. SPV modules with a tilt of 25 degrees mounted on roof top of Reference Building

The SPV Array Power of 100 KWp having 13-14% module efficiency, battery voltage of 240 V and 10 year warranty for 90% rated output has been installed on the roof top of the building. Eight hours of operation from solar system is covering fans, tube lights, and is working efficiently since May 7th, 2013. SPV array is grouted on support structures on the roof with a tilt of 25 degrees to avoid shadow on other rows of panels (Fig. 3).

Modules are mounted by corrosion resistant galvanized steel frame, in panels of five each and connected together in series in daisy chain manner. SPV has suitable number of Crystalline Silicon solar cells connected in series and hermetically sealed with toughened glass on top and lamination on back. Two ends of modules are brought to Panel Junction Box mounted on panel structure. The batteries, charge controller and inverter are placed inside a room on ground floor of the building. Solar cables have been designed to resist high mechanical load and abrasion.

Power Conditioning Unit provides three-phase AC power to specified loads to reduce dependency on conventional power in the event of power failures. The system incorporates a front to panel display with LEDs and a switch to indicate the "operational status" and "fault status". When the solar energy is not available due to insufficient sunlight or cloudy days, the system enables the battery to meet the demand. The cost – benefit analysis of solar PV system is given in Table 5.

Further analyses reveal that the SPV system is contributing to keep the top floor room temperature 3 º to 5°C less as compared to the roof without SPV panels in the library block.

VIII. CONCLUSIONS

The research presented in this paper has investigated the green retrofitting potential in CSIR research laboratory buildings by doing the real – time studies. The generic green retrofit strategies are proposed to improve thermal comfort by reducing heat gain in summers and heat loss in winters. The use of energy efficient fixtures could significantly reduce the energy consumption substantially. The SPV is not only contributing as sustainable energy source but also improving the inside comfort on top floor. Hence, the proposed strategies if implemented in all the 37 CSIR research laboratories of India, will lead to significant energy and water savings, improve the thermal comfort and productivity of the staff.

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First Author

Mr. Ashok Kumar *is presently Senior Principal Scientist & Head, Architecture & Planning, at CSIR-CBRI, Roorkee. He is B.Arch. Gold Medalist from JNTU, Hyderabad and has done MURP from Univ. of Roorkee. He specializes in energy efficient design, housing, prefab technologies and green retrofits. He is a member of many committees of BIS including ECBC and contributed in the formation of Code on Use of Glass in Buildings. He has published more than 50 papers in Journals, Conferences and Seminars. He is also Visiting Faculty at the Indian Institute of Technology (IIT), Roorkee.*

Second Author

Dr. P.S.Chani*, is working as Associate Professor in the Dept. of Architecture and Planning, IIT Roorkee. Dr. Chani obtained his B.Arch. , M.Arch. and Ph.D. from IIT Roorkee. His major area of research is energy in buildings, exploring both embodied and operating energy. The present focus is on energy assessments of buildings through baseline & simulation modeling and its application for an energy efficient building. He is guiding many research scholars.*

Third Author

Dr. Rajesh Deoliya*, working as Principal Scientist & is presently, Scientist Incharge, CSIR- CBRI, Extension Centre, New Delh. He has done Ph.D. form IIT Delhi in Structural Engineering during 1996. He specializes in wind resistant design of structures, earthquake resistant design, service life prediction for concrete structures, repair and rehabilitation of buildings, safety and reliability of structures, design of lattice steel microwave towers, and quality assurance of buildings. He has contributed in the formation of Code on Use of Glass in Buildings. He has published several papers in Journals & Conferences.*

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